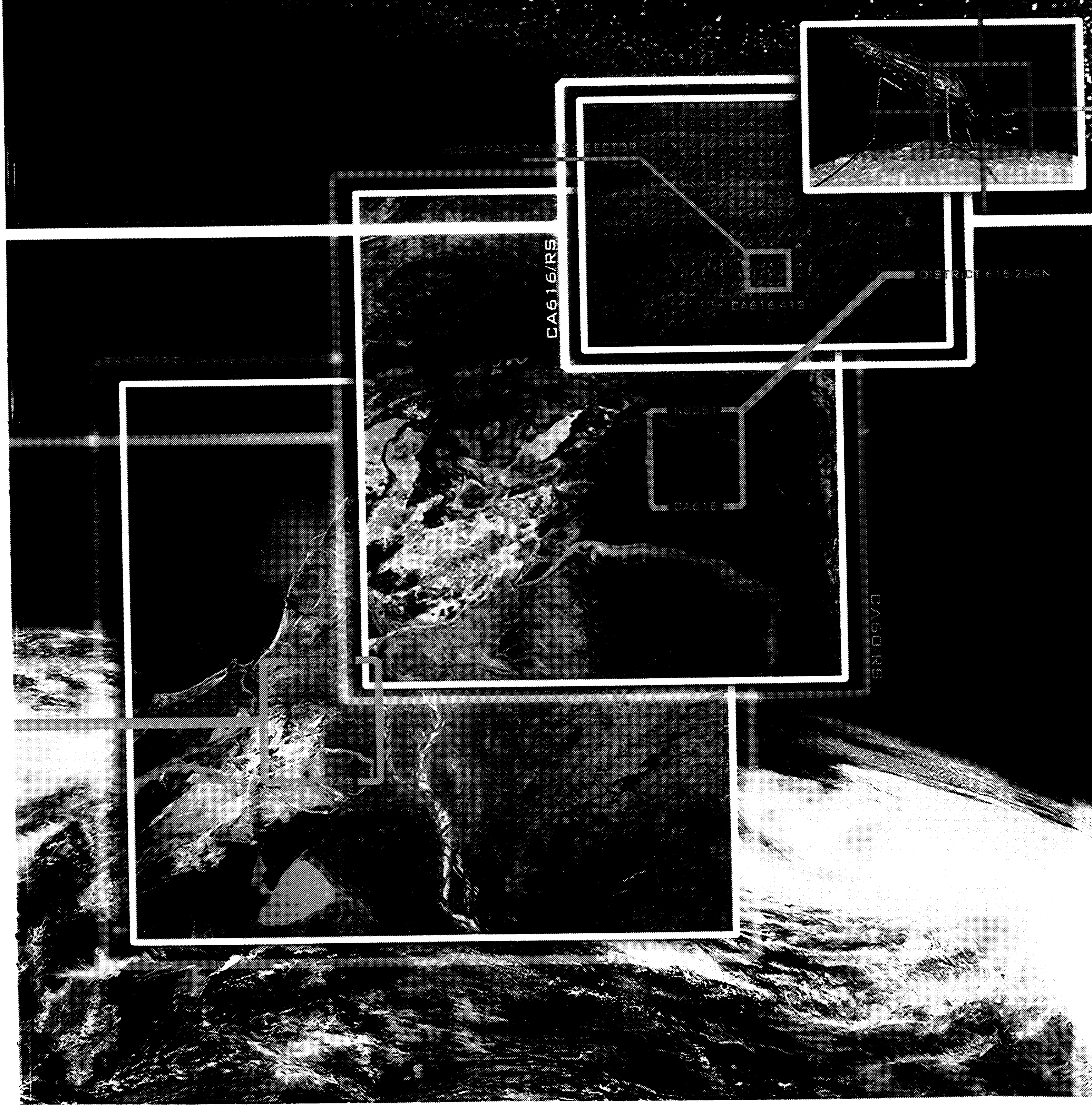
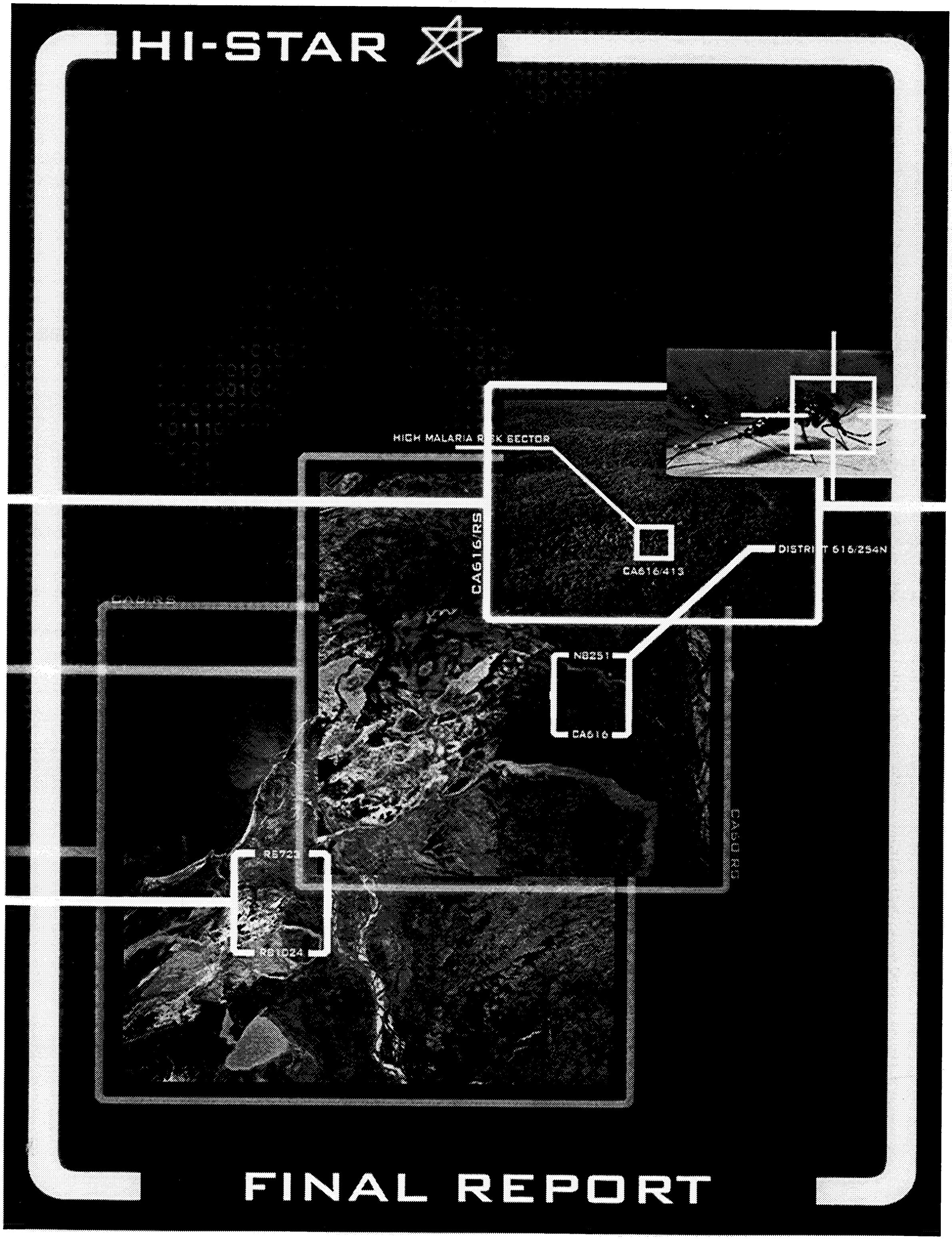
HI-STAR

HEALTH IMPROVEMENTS THROUGH SPACE TECHNOLOGIES & RESOURCES

FINAL REPORT





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International Space University
Strasbourg Central Campus
Attention: Publications
Parc d'Innovation
Boulevard Gonthier d'Andernach
67400 Illkirch-Graffenstaden
FRANCE

Tel: + 33 (0) 3 88 65 54 30
Fax: + 33 (0) 3 88 65 54 47

http://www.isunet.edu

http://www.hi-star.org

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PROJECT SPONSORS

NASA Stennis Space Center, USA

PROJECT FACULTY AND TA

1st Half Co-chair	Olga Zhdanovich
1st Half Co-chair	Dr. U.R. Rao
2nd Half Co-chair	Dr. Vern Singhroy
Teaching Assistant	Richard Giroux

Faculty, TA's, Staff, Advisors

Dr. Phillipe Achilleas
Eric Batosch
James Burke
Juan de Dalmau
Felipe Hernandez
Dr. Walter Peeters
Gudrun Weinwurm
Dr. Ray Williamson

External Experts

Jim Keravala	Surrey Satellite Technology Ltd.
Marlies Craig	Mapping Malaria Risk in Africa (MARA)
Dr. Mark Helmlinger	NASA Jet Propulsion Laboratory
Dr. Susan Helmlinger	University of Southern California
Dr. Cindy Schmidt	NASA Ames
Dr. Louisa Beck	CHAART, NASA Ames
Dr. Richard Alderslade	World Health Organization
Dr. Awash Teklehaimanot	World Health Organization
Dr. Andrea Egan	Multi-lateral Initiative for Malaria (MIM)

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Supporting Organizations

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List of Authors

Matteo ALESSANDRINI	ITALY	M.Eng Student, Mechanical Engineering, University of Bologna, Italy Participation in ESA Outreach activities
Edward ANDERSON	U.K	M.Eng Aerospace Engineering, 2002, University of Bristol, UK
Olufemi AROSANYIN	NIGERIA	B.Eng Electrical Electronics, 1997, Federal University of Ilorin Nigeria Telecoms Engineer, TTI Ltd, Abuja Nigeria
Atsushi BABA	JAPAN	M.Eng Mechanical Engineering, 1999, Kyushu University, Japan Thermal Engineer, NASDA, Tsukuba Space Center
Jean-Pierre BALLEY	FRANCE	Mechanical Engineer 1991, University of Technology of Compiègne, France Quality Assurance in Launchers & Spacecraft projects, EADS les Mureaux, France
Pier BARGELLINI	ITALY	Master Aeronautical Engineering, 1996, Università degli Studi di Pisa, Italy ENVISAT Satellite Operations Engineer, ESA, European Space Operations Centre (ESOC), Darmstadt, Germany
Hammad BENCHEKROUN	MOROCCO	M.Eng Telecom, 1988, Mohamadia School of Engineers, Morocco M.Sc Physics in Remote Sensing, 1989, Paris VII University, France Data Management Division Head, Royal Centre for Remote Sensing, Morocco
Annie BERNARD	FRANCE	Information and Communication, Bordeaux III Directorate of Launchers, European Space Agency
Barbara BROWN	USA	MPH, Public Health, Maternal Child Health, University of California, Berkeley, USA M.S. Occupational & Environmental Health, University of California, San Francisco, USA M.S. Space Studies, University of North Dakota, USA

Linh BUI	USA	B.A. Communications, 2002, California State Polytechnic University, Pomona
Marc CALON	BELGIUM	M.Sc in Electronic Engineering, 1981, Catholic University of Leuven, Leuven, Belgium M.Sc in Aeronautics and Space, 2001, Vrije Universiteit Brussel, Brussels Process Engineer, Sidmar, Gent, Belgium
Rémi CANTON	FRANCE	M.Sc Aerospace Eng, 2000, SUPAERO, Toulouse, France Guidance-Navigation-Control Engineer, Titan, NASA-JSC, Houston
Patrick CHATARD-MOULIN	FRANCE	Engineering degree from FAFA and Telecom Paris Engineering School Professor of Space Communications at the French Air Force Academy (FAFA) Engineering Officer in the French Air Force
Ed CHESTER	U.K	B.Sc. Physics, 1995, University of Durham, UK M.Sc. Electronics, 1996, University of Newcastle, UK Ph.D. High-Speed Signal Processing Architecture and Computer Arithmetic, 2002, University of Newcastle, UK Full-time searching for space job, part-time I.T. Manager
Alejandro DIAZ	USA/PERU	B.Sc, Aerospace Engineering, 1998, UCLA, USA M.Sc, Aerospace Engineering, 2001, USC, USA M.A, Latin American Studies, ECD 2003, UCLA, USA Engineer/Scientist, Extravehicular and Crew Systems Team, International Space Station Program, Boeing, Huntington Beach
Artu ELLMANN	ESTONIA	Dipl.Eng. in Geodesy, 1993, Moscow State Unversity of Geodesy and Cartography, Russian Federation Eng.Lic. in Geodesy, 2001, Royal Institute of Technology (KTH) in Stockholm, Sweden Ph.D Student, KTH in Stockholm, Sweden
Soraya ELLOUZE	FRANCE	LLB, 1996, University of Paris V, France LLM, 1998, McGill University, Canada
Daniel ESCOLAR BLASCO	SPAIN	M.Sc Aeronautical Engineering, 1997, Universidad Politecnica de Madrid, Spain Mechanical Engineer, Atos Origin Engineering Services, ESA/ESTEC, The Netherlands

Allison GANDEY	CANADA	B. Journalism, 1998, Carleton University, Ottawa, Canada M.Journalism Student, Carleton University Medical Journalist
Thibaut GIRARD	FRANCE	M.Sc Aerospace Eng, 2002, SUPAERO, Toulouse, France
Carla HAROZ	USA	B.S Aerospace Engineering, 1996, University of Texas at Austin B.A. Russian Language and Literature, 1996, University of Texas at Austin M.S. Aeronautics and Astronautics, 1998, MIT ISS Flight Controller, NASA JSC, Houston, TX
Neil HAZAN	CANADA	B.A.,1997, McGill University, Canada BCL/LL.B Student, McGill University, Canada
Bérengère HOUDOU	FRANCE	Electrical Engineering Degree, 2001, Supelec, France M. Sc in Astronautics, 2002, Massachusetts Institute of Technology, USA
Anton ILIN	RUSSIA	Engineering/Bachelor of Management, 2001, Moscow Aviation Institute Babakin Space Center. System Design Analysis Department. Moscow Aviation Intitute. Phd student. Since 2001
Arisa ITO	JAPAN	B.Eng Mechanical engineering, 2002, Tohoku University M.Eng Student, Tohoku University
Philippe JAMES	FRANCE	M.Eng, 1993, Ecole Centrale Paris, France PhD in acoustics and vibrations, 1998, Institute of Sound and Vibration Research, Southampton, UK Nozzle Extension Design Manager, SNECMA, France
Alison JENNINGS	CANADA	B.Sc Human Kinetics, University of Ottawa M.Sc Exercise Physiology, University of Ottawa & Ottawa Health Research Institute

Kevin KOZAK	CANADA	B.Sc Space Science, 2001, Royal Military College of Canada M.Sc Space Operations, 2002, RMC Canadian Air Force Student Pilot
Manon LAROCQUE	CANADA	B. Comm, 1997, University of Ottawa, Canada International MBA, 1998, Univ. of Ottawa, Canada Manager International Relations, Canadian Space Agency, St-Hubert, Quebec, Canada
Birgit LOECKER	AUSTRIA	B.A., 2000, Vienna University of Business Administration and Economics Market Research Project Management, since 2000, ARC Seibersdorf research GmbH., Austria
Ammon MADSEN	USA	B.Sc. Mechanical Engineering, 2000, Utah State University Systems/Integration Engineer, Sea Launch, Long Beach, CA
Atsushi MAMIYA	JAPAN	B.Eng Geosystem, 1997,Univ of Tokyo, Japan M.Eng Geosystem, 1999,Univ of Tokyo, Japan Systems Engineer, JSAT, Japan
Sabri MEKAOUI	BELGIUM	B.Sc Physics, 1996, University of Tunis, Tunisia Degree Mathematics, 2000, University of Liege, Belgium M.Sc Space Studies, 2002, CSL University of Liege, Belgium Project Scientist, Royal Meteorological Institute of Belgium, Brussels
France MIGNARD-CANTON	FRANCE	M. Sc Telecommunications and Networks Engineer, 2001, Ecole Centrale d'Electronique ECE, Paris, France
Ha Viet NGUYEN	VIETNAM	Telecom Engineer, 1986, Telecommunication College, Vietnam Master of Eng,1994, Hanoi University of Technology HUT, Vietnam Deputy Director,VINASAT project, VNPT, Vietnam
Shane O'SULLIVAN	IRELAND	B.Eng Mechanical Engineering, 1999, University College Dublin, Ireland PhD student, Pollution Control, University College Dublin, Ireland

Giuseppe OTTAVIANELLI	ITALY	M.Eng Aerospace, 2002, University of Manchester, UK M.Sc Astronautics and Space, Student, Cranfield University, UK
Thierry PICHON	FRANCE	Mechanical Engineering, 1988, E.N.S.A.M., France Mastère in Aerospace Mechanics, 1989, E.N.S.A.E., France Composite Nozzles Program Manager, Snecma Propulsion Solide, Le Haillan, France
Armine POGHOSYAN	ARMENIA	Diploma in International Law, 1994, Economic and Law University of Republic of Armenia Chief Law Expert for Juridical Department of the Ministry of Transport and Communications of Armenia
Stephan SAUPE	GERMANY	Diploma in Physics 1991, University of Bonn, Germany PhD in Physics 1994, University of Bonn, Germany German Aerospace Center (DLR), Strategy Development, Cologne, Germany
Martin STIRN	AUSTRIA	M.Sc Student, Carinthia Tech Institute, School of Geoinformation, Austria
Aksel STRAUME	NORWAY	Candidatus Magisterii, 2000, Norwegian University of Science and Technology (NTNU), Norway Candidatus Scientiarum, 2002, Norwegian University of Science and Technology (NTNU), Trondheim, Norway
Yuri TAKAYA	JAPAN	B.A. in International Law, Waseda Univ. 1997 Japan LL.M. in International Air and Space Law, Leiden Univ. 2001 in the Netherlands
Sylvain TEODOMANTE	FRANCE	M.Sc Bio-Medical/Software Eng, 1989, University of Technology of Compiegne (UTC) Industrial System Control D.E.A. Quality S/W Manager LEO satellites operations engineer. (CNES)
Damien THEUREAU	FRANCE	M.Sc Aerospace Eng, 2002, SUPAERO, Toulouse, France

Hiroaki UMEHARA	JAPAN	PhD Science, 1998, in Theoretical Astrophysics, National Astronomical Observatory, Japan Researcher of orbital mechanics and optical monitoring, in Communications Research Laboratory, Japan
Wencke VAN DER MEULEN	NETHERLANDS	M.Sc Aerospace Engineering -- Satellite Systems and Astrodynamics, Delft University of Technology, The Netherlands, 2000 Galileo Project coordinator, Dutch Agency for Aerospace Programmes, The Netherlands
Johannes VAN ES	NETHERLANDS	M.Sc Engineering Physics, 1995, Twente University, The Netherlands. Process Engineering Design Course, 1997, Twente University Research Engineer, Thermal Control Group, Space Divsion, National Aerospace Laboratory, The Netherlands.
Jonatan WESTMAN	SWEDEN	M.Sc Space Eng, 2002, Luleå University of Technology, Sweden B.Sc. Student, Luleå University of Technology
David WONG	HONG-KONG	B.Sc Architecture, 2002, University of Bath, UK MA Architecture student 03-05, Univerisy of Bath, UK Freelance graphic designer
Julielynn WONG	CANADA	B.Sc Biology, 1997, York University, Canada Medical Student, Queen's University, Canada
Bent ZIEGLER	DENMARK	M.Sc Control Engineering, 2001, Technical University of Denmark Ph.D. Student, Technical University of Denmark.
Simona ZOFFOLI	ITALY	M.Sc Physics, 1997, University of Rome "La Sapienza", Italy Earth Science Programms, Italian Space Agency, Italy

Faculty Preface

At each summer session program of the International Space University, students carry out two design projects intended to give teamwork experience and to generate analyses and recommendations on topics of current interest in the world's space programs. In 2002 the two projects were about astrobiology and the use of space systems in improving human health. This document presents the results of the *HI-STAR: Health Improvements through Space Technologies and Resources,* design project.

Given the diversity of possible applications of space technology to health problems, the students' first task was to define a manageable scope for their project. After a review of many possibilities they decided to focus on the development of a global strategy to help combat malaria using space technology. Malaria is a major global problem especially in developing countries, and one for which earth observation, communication and positioning systems, integrated with other existing initiatives, can assist in combating the disease. The design project team carried out intensive information searches, with the aid of advisors, literature and Internet sources, to discover where and how ground, airborne and space systems could most effectively integrate and supplement the world's existing attack on malaria.

To provide meaningful and specific results, the team chose as examples four very different countries where malaria is a serious impediment to a healthy and productive society: Nigeria, Kenya, India and Indonesia. The case studies of these countries demonstrate a variety of the challenges and opportunities facing the malaria-ridden tropical world. It is hoped that the recommendations suggested by the students will be useful to the agencies dealing with human health and space technologies.

We, the design project faculty, advisors and teaching assistant, are honored and proud to have been associated with this talented and energetic group of students.

U.R. Rao
Co-chair

Olga Zhdanovich
Co-chair

Vern Singhroy
Co-chair

Richard Giroux,
Teaching Assistant

Student Preface

The 2002 Summer Session Program was held at the California State Polytechnic University in Pomona, California, USA. From the first of July to the thirty-first of August, Design Project 2 students occupied their time investigating the application of Space Technologies and Resources in the battle against Malaria. This document, entitled *'HI-STAR – Health Improvements through Space Technologies and Resources'* is one of two final reports produced by the International Space University's 2002 Summer Session Program. This report is the culmination of many weeks of intense effort, cooperation, some heartache, and ultimately satisfaction in a paper to be proud of.

HI-STAR was authored by 53 students and professionals from 20 different countries. Due to this multi-cultural forum, the development process for this document was unique. The paper was shaped by authors of various outlooks, experiences, opinions and many different disciplines. The different perspectives acquired as a result of working in such a multidisciplinary environment were invaluable. Friendships were created, bonds formed, new insights gained, and dreams born. Our ISU experience was truly memorable and will serve us well in our role as future ambassadors of space development.

This Final Report would not have come to fruition without the direction, assistance, support and insight of many ISU faculty members, staff, visiting lecturers, alumni and friends. Special mention must be made of Olga Zhdanovich, Vern Singhroy, Udipi Rao, and Richard Giroux who served as instrumental members of our Design Project. For their dedication, guidance and assistance we are especially grateful.

We believe that we have produced a report that can influence future developments and policies regarding the use of space technology towards improving human health.

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List of Abbreviations

ACTmalaria	Asian Collaborative Training Network for Malaria
ACTS	ArteMISnin-Based Combination Therapies
ADDS	Africa Data Dissemination Service
ADM	Acoustical Detection Method
AMPAC	Agency for Malaria Prevention and Control
AMREF	African Medical and Research Foundation
ARMA	Atlas du Risque de la Malaria en Afrique
AVHRR	Advanced Very High Resolution Radiometer
BADEA	Arab Bank For Economic Development In Africa
BRGM	Bureau de recherches géologiques et minières
BMDP	Biospheric Monitoring and Disease Prediction Project
CARPE	Central Africa Regional Program for the Environment
CEA	Commissariat à l'Energie Atomique
CHAART	Charter for Health Application of Aerospace Related Technologies
CHESTRAD	Center for Health Sciences, Training Research and Development
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement
CMCs	Community malaria committees
CNES	Centre National d'Etudes Spatiales
COPUOS	Committee on Peaceful Uses of Outer Space
CSA	Canadian Space Agency
DAAC	Land Processes Distributed Active Archive Center
DALY	disability adjusted life year
DBMS	Database Management System
DEPANRI	National Council for Aeronautics and Space of the Republic of Indonesia
DFID	UK Department for International Development
DMC	Disaster Monitoring Constellation
DOMC	*Division of Malaria Control*
DOS	Department of Space
DOT	Department of Telecommunications
DUP	Data User Programme
EADS	European Aeronautic Defence and Space Company
EANMAT	East African Network for Monitoring Anti-malarial Treatment Efficacy
ECOWAS	Economic Community of West African states
EC-RMCP	European Commission's Regional Malaria Control Programme
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
ENSO	El Niño Southern Oscillation
EPI	Epidemiology Program
EROS	Earth Resources Observation Center

List of Abbreviations continued

ERS	European Remote Sensing satellite
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological
FAO	Satellites
FGDC	U.S. Federal Geographic Data Committee
FEWS	Famine Early Warning System
GIS	Geographic Information System
GMES	Global Monitoring for Environment and Security
GMHH	Global Monitoring and Human Health
GNSS	Global Navigation Satellite Systems
GDP	Gross Domestic Product
GMES	European Global Monitoring for Environment and Security
GNP	Gross National Product
GPS	Global Positioning System
HI-STAR	Health Improvements through Space Technologies and Resources
IAF	International Astronautical Federation
IAMIS	Integrated Advanced Information Systems
ICC	*Inter-Agency Coordinating Committee for Malaria*
IDA	International Development Association
IDRC	International Development Research Center
IEC	Information, Education and Communication
IMCI	Integrated Management of Childhood Illness
INRA	Agronomic Research Institute
INSAT	Indian National Satellites System
IRD	Institut de recherche pour le Développement
IRS	Indian Remote Sensing
ISO	International Organization for Standardization
ISRO	Indian Space Research Organization
ISU	International Space University
ITNs	Insecticide-treated mosquito nets
KMIS	Kenyan Malaria Information System
KRCS	Kenyan Red Cross
JERS	Japanese Earth Resources Satellite
LAN	Local Area Network
LAPAN	Indonesian National Institute of Aeronautics and Space
LEO	Low Earth Orbit satellites
LIDAR	Light Detection And Ranging instrument
LSDI	Lubombo Spatial Development Initiative
MARA	Mapping Malaria Risk in Africa
MCP	Malaria Control Programs

List of Abbreviations continued

MEDSAT	MEDical SATellite
MEWS	Malaria Early Warning System
MIM	Multi-lateral Initiative for Malaria
MIS	Management Information System
MISI	Malaria Information System Initiative
MMV	Medicines for Malaria Venture
MSF	Medecins Sans Frontieres
NAMP	National Anti-Malaria Program
NASA	National Aeronautics and Space Administration
NASRDA	Nigerian Space Agency
NCRS	National Center for Remote Sensing
NDVI	Normalized Differential Vegetation Index
NGO	Non-governmental organizations associated with the United Nations
NIH	National Institute of Health
NLM	National Library of Medicine
NMEP	National Malaria Eradication Program
NMS	National Malaria Strategy
NNRMS	National Natural Resources Management System
NOAA	US National Oceanic And Atmospheric Administration
OAU	Organization of African Unity
PHS	Public Health Service
RAPIDS	Real-time Acquisition and Processing Integrated Data System
RBM	Roll-back Malaria programme of the World Health Organisation
RCMRD	Regional Center for Mapping of Resources for Development
RMTC	Regional Meteorological Training Center
ROM	Rough Order of Magnitude
RS	Remote Sensing
SARs	Synthetic Aperture Radars
SCT	Satellite Communications Terminal
SEA	South East Asia
SPL	low spectrum level
SST	Sea Surface Temperature
SSTL	Surrey Satellite Technology Ltd
STPI	Software Technology Parks of India
S2E	Space Surveillance of Epidemics
TDR	Special Program...
TDR	Special Program for Research and Training in Tropical Diseases
TRIPS	Trade-Related Aspects of Intellectual Property Rights
TRP	Technical Review Panel

List of Abbreviations continued

TT&T	Technology Transfer and Training
TWG	Transitional Working Group
UN	United Nations
UNDP	United Nations Development Program
UNEP	United Nations Environmental Program
UNICEF	United Nations Children's Fund
USAID	US Agency for International Development
VITA	Volunteers In Technical Assistance
VSATs	Very Small Aperture Terminals satellites
VSNL	Videsh Sanchar Nigam Limited
WHO	World Health Organization
WIPO	World Intellectual Property Organization
WSF	World Space Foundation
WWF	World Wildlife Fund

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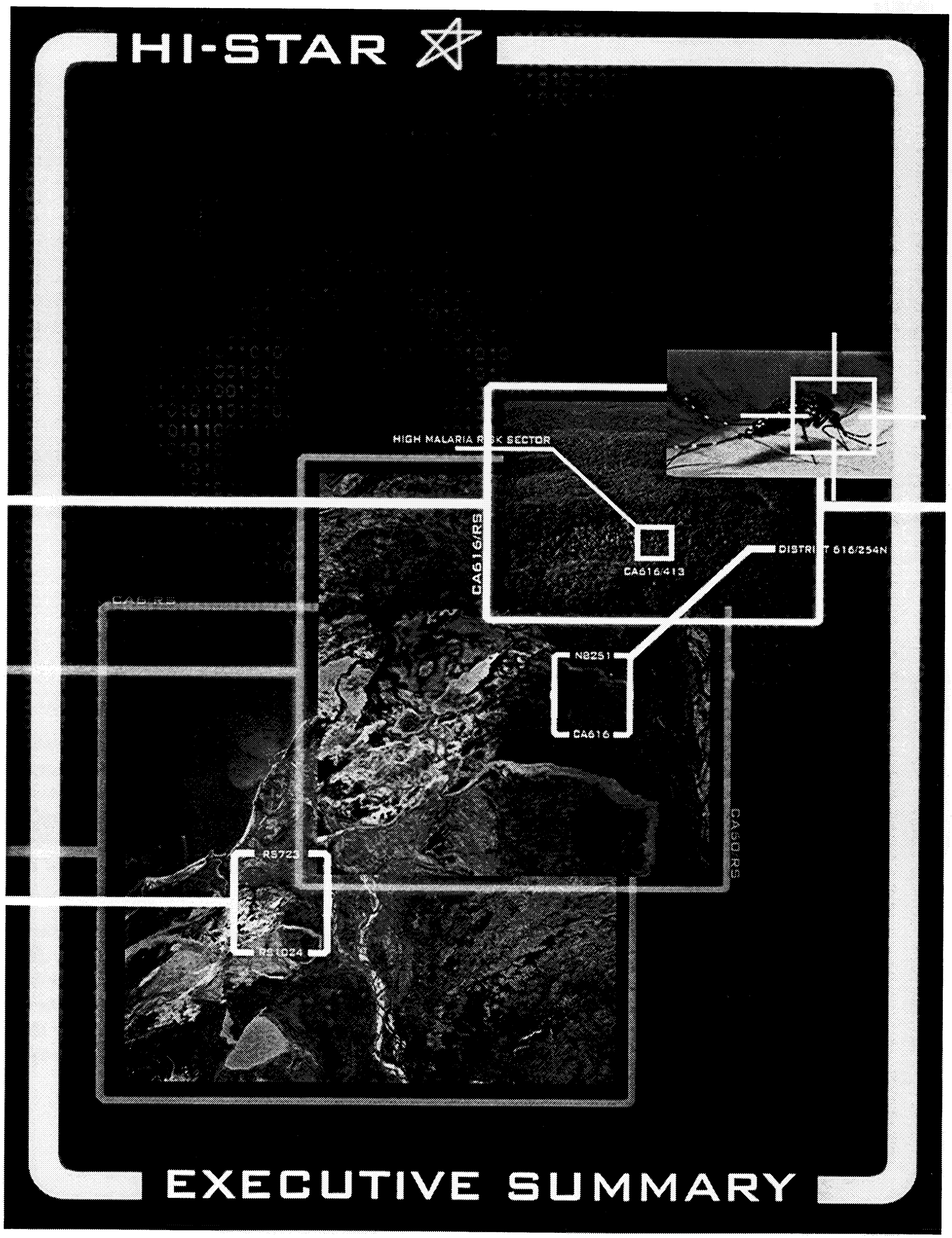
HI-STAR
HIGH MALARIA RISK SECTOR
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RS1024
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African children at risk of malaria. Photo courtesy of the World Health Organization

When Malaria Hits Home

At first, Maria thought she had the flu. She felt so tired, her muscles ached and although she had a fever, she felt chilled all the time. Despite her woes, the mother of seven persevered and continued working the long hard days to which she had become accustomed. But it didn't take long before her condition worsened. Eventually, her head hurt so badly that she could no longer work in the field with her family. Maria was forced to rest in bed. Then the nausea hit. Her whole body shook while beads of sweat seeped into the bed. Maria called out and writhed in pain. Her young daughter stayed home to tend to her ailing mother.

Maria's husband furrowed his brow as he looked at his young wife. Her usually beautiful dark skin looked pale and yellow. It was a color he had seen before – it was the color of death. He placed his head in his hands and wept quietly. His own parents had died of malaria when he was just a boy so he knew the symptoms well. And just this year he and Maria had lost their beloved baby boy to the disease. The child had suffered obscene bouts of diarrhea before the seizures started and he went into a coma. He had died shortly after. Surely not Maria too. Surely not Maria.

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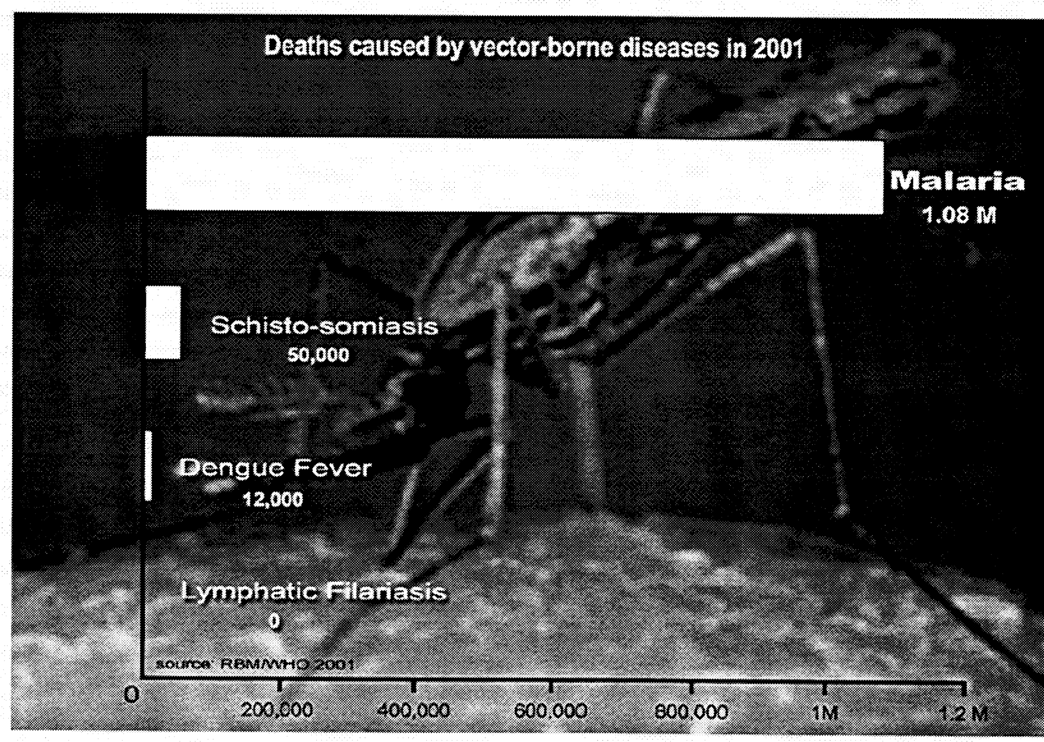
This account is based on a true story. Malaria causes more than 300 million acute illnesses and at least one million deaths annually. Approximately 40% of the world's population is at risk of malaria. Every single second of every single day, ten people are infected with malaria. Many of these cases involve children who do not survive [Roll Back Malaria and the World Health Organization, 2002].

A Dangerous Disease

The word malaria comes from the Italian *mala aria* or bad air because it was once thought the disease came from breathing unhealthy swamp air [Wernsdorfer, 1980]. We have since learned that malaria is a parasitic disease spread by the female *Anopheles* mosquito. When the mosquito bites an infected person, it ingests microscopic malaria parasites living in the person's blood. The mosquito then transmits the disease to other humans.

Malaria affects the health and wealth of individuals and nations alike. It is both a disease of poverty and a cause of poverty. It has measurable direct and indirect costs, and has recently been shown to be a major constraint to economic development. This has meant that the gap in prosperity between countries with malaria and those without has become wider every year.



Malaria Moving North

Malaria was once even more widespread throughout the world, but it was successfully eliminated from many countries with temperate climates during the mid 20th century. Today, malaria is predominately found throughout the tropical and sub-tropical regions of the globe. Over the past ten years, malaria outbreaks have started moving back into the northern hemisphere. Cases have been reported in northern India, Turkey and Russia. Occasional outbreaks have also been reported in Europe and North America [RBM/WHO, 2002].

Malaria transmission is possible when weather conditions support the growth of *Anopheles* mosquitoes. When people arrive from malaria-endemic countries, a malaria parasite reservoir becomes available in non-infected areas.

Short-term climate variations such as El Niño-Southern Oscillation (ENSO) also affect the distribution and intensity of malaria in some regions. El Niño is a disruption of the balance of the ocean-atmosphere in the tropical pacific, which affects the weather and climate. Long-term changes such as global warming may also influence the emergence of malaria, which tends to increase with temperature changes.

Malaria, despite all of its devastating consequences, is a preventable disease. This report, Health Improvements through Space Technology And Resources (HI-STAR) demonstrates one way this can be done.

HI-STAR

> *If you think you are too small to make a difference, try sleeping in a closed room with a mosquito.*
>
> *– African Proverb*

Like the tiny yet powerful mosquito, HI-STAR is a small program that aspires to make a difference. Timely detection of malaria danger zones is essential to help health authorities and policy makers make decisions about how to manage limited resources for combating malaria.

In 2001, the technical support network for prevention and control of malaria epidemics published a study called "Malaria Early Warning Systems; Concepts, Indicators and Partners." This study, funded by Roll Back Malaria, a World Health Organization initiative, offers a framework for a monitoring and early warning system. HI-STAR seeks to build on this proposal and enhance the space elements of the suggested framework. It is the work of fifty-three professionals and students from the International Space University's 2002 Summer Session Program held in California, USA.

Our mission is to develop and promote a global strategy to help combat malaria using space technology

HI-STAR focuses on malaria because it is the most common and deadly of the vector-borne diseases. Malaria also shares many commonalities with other diseases, which means the global strategy developed here may also be applicable to other parasitic diseases.

HI-STAR would like to contribute to the many malaria groups already making great strides in the fight against malaria. Some examples include: Roll Back Malaria, The Special Program for Research and Training in Tropical Diseases (TDR) and the Multilateral Initiative on Malaria (MIM). Other important groups that are among the first to include space technologies in their model include: The Center for Health Application of Aerospace Related Technologies (CHAART) and Mapping Malaria Risk in Africa (MARA).

Malaria is a complex and multifaceted disease. Combating it must therefore be equally versatile. HI-STAR incorporates an interdisciplinary, international, intercultural approach.

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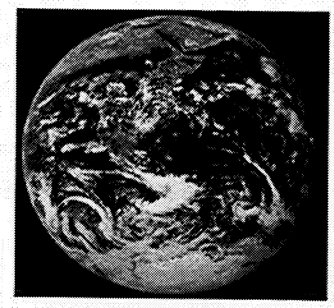
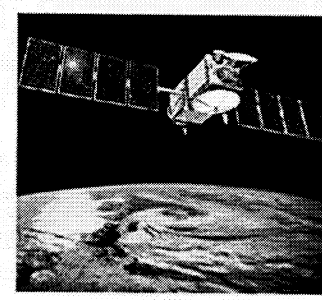
An Interdisciplinary, International, Intercultural Initiative



A single solution for malaria may never exist. As a result, combating this disease requires a combination of tools that range from Earth observation satellites to airborne and ground-based measures including pesticides, bed nets and various medical treatments.

HI-STAR is interdisciplinary in that it addresses all aspects of malaria from a scientific, engineering, economic, medical, regulatory, social, political and organizational perspective. It recognizes and addresses the complex interactions among specialties.



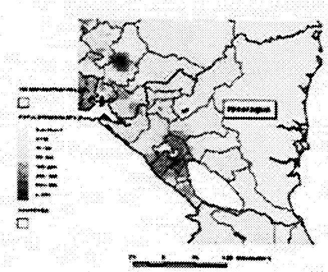
Our concept is international. It is an approach developed by an international group of professionals and students, including people from developing countries, who understand the complexities of working within and among many nations. The strategy, while global in structure, has been designed to meet the individual needs of specific regions.

HI-STAR is intercultural. It is based on a strategy that can be applied to countries with distinct histories, religions and traditions. HI-STAR seeks to unite people in preventing malaria using a global framework. The strategy is flexible, however, in that it allows individual regions to use a unique local approach. HI-STAR's global strategy is general in principle and highly customizable in practice.

Why Space Technology?

From space, we can see the Earth is united, undivided by borders, unrestrained by political boundaries. The transnational nature of space mirrors the transnational nature of vector-borne diseases, which are spreading indiscriminately irrespective of national frontiers.

By looking at the globe from space, we achieve a new perspective. We can see things that would not be possible to view up close. Earth observation technologies have been used for many years and have been implemented for a wide range of purposes. They are most commonly used for monitoring natural resources, agriculture, oceanography, mapping the weather and natural disasters.



Other space technologies such as Global Navigation Satellite Systems (GNSS) may support malaria monitoring. For example, it is possible to locate infected areas and treatment facilities in remote regions.

Malaria disease dynamics and distributions are related to environmental variables. Water observation is key because mosquitoes lay their eggs in stagnant bodies of water. Weather plays an important role in the quantity and distribution of *Anopheles* mosquitoes, which transmit diseases.

High temperatures, humidity, precipitation and wind promote infestations of these dangerous insects. Temperature determines

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the rate at which mosquitoes develop into adults, the frequency of their blood feeding, the rate at which the parasites are acquired and the incubation time of the parasite [Patz et al., 2000].

With remote sensing images, we can monitor environmental conditions that support the growth of mosquito populations. The information gathered this way is of limited value, but integrating it in a Geographic Information System (GIS) makes it a useful tool. Figure 1 depicts the data that would feed into such a system.

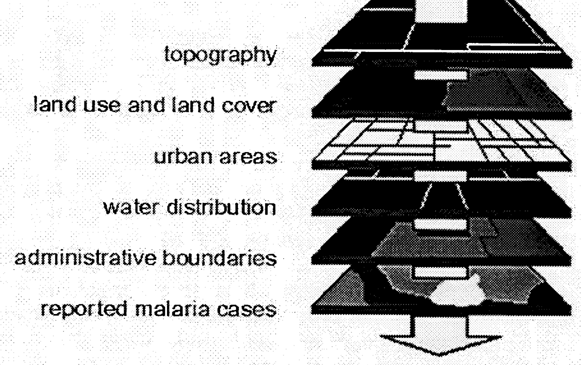


Figure 1: Malaria specific GIS data structure

Malaria Information System

GIS is an information system that assembles, stores, manipulates and displays spatial data. By integrating malaria specific information in a GIS, a Malaria Information System (MIS) can be developed. A model of the system is shown in Figure 2.

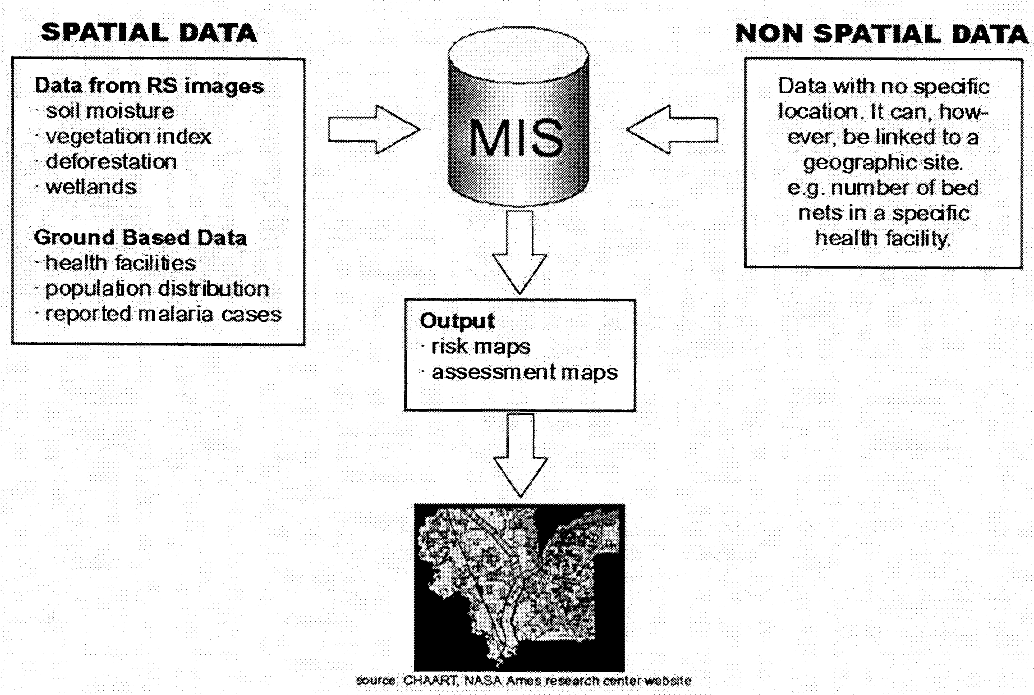


Figure 2: Malaria Information System

Integrating environmental data gathered by remote sensing satellites enhances the system and helps create:

- low cost risk maps
- weather forecasts that provide malaria early warnings

HI-STAR suggests developing a MIS as a low cost tool to help organizations plan their efforts to fight malaria. The success of risk monitoring is only as effective as the ability to transmit information to those who can put preventive measures in place. MIS seeks to develop an information product that links the technical to the interpersonal by presenting data in a comprehensive form.

How MIS findings are presented is a key component of the model. Malaria risk maps are of little use if they are not understood. All MIS output must be simplified and comprehensively communicated. This can be done using attractive illustrations and graphs.

MIS findings should also be customized according to individual user needs and requests. Users will be encouraged to offer feedback so that MIS outputs can be enhanced to meet specific requirements. Feedback will help customize MIS so that it is useful in diverse regions with unique concerns.

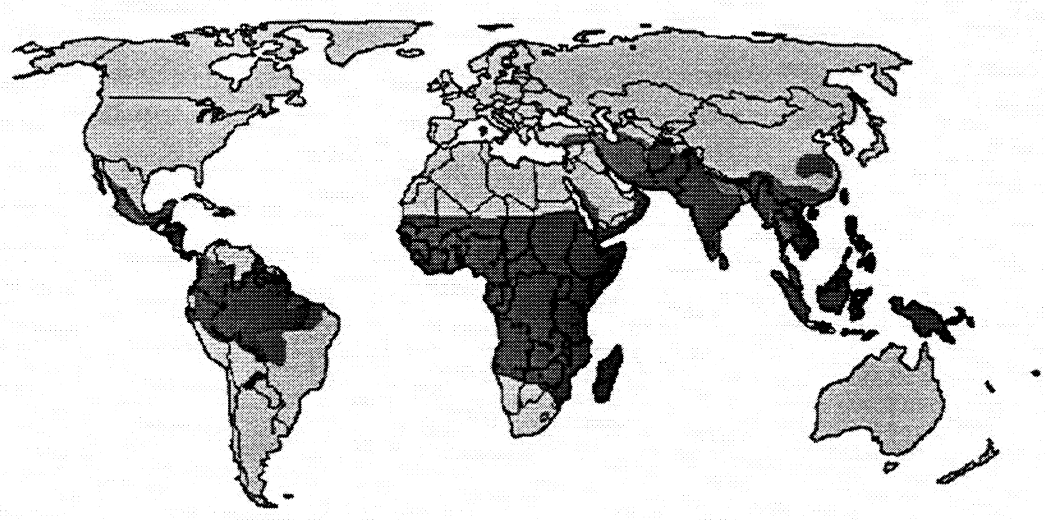
In the past, the costs of using remotely sensed space images were too high for such an application. However, reduced data costs and improved image and GIS software are bringing down these expenses.

HI-STAR Strategy

Our strategy recommends the increased use of space technology in conjunction with current initiatives. We seek to link the information from space technology to the people who need it most in a timely and comprehensive form so that health authorities and policy makers can manage resources for combating malaria more effectively.

For a strategy to succeed, it must meet the needs of those involved. In the spirit of HI-STAR's interdisciplinary, international, intercultural design, we studied the situation of a number of malaria endemic countries.

The vast majority of the world's population lives in Asia where malaria risk is significant. Yet 90% of all malaria cases remain in Africa [RBM/WHO, 2002]. We studied two countries from each region. Countries were chosen based on three factors, malaria burden, population at risk, and space infrastructure.



WHO malaria distribution map 2001

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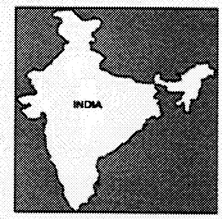
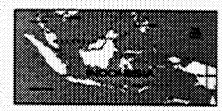
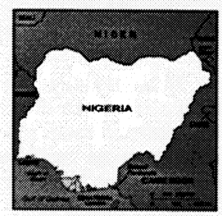
In an effort to achieve a complete picture, we looked at countries with varying circumstances. In Asia, we selected India and Indonesia and in Africa, we chose Nigeria and Kenya.



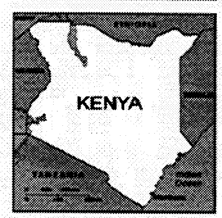
India has a population of 1 billion people where about 98% of the population is at risk of malaria. It has an extensive space program that remains unused for malaria risk mapping.



Indonesia is the world's fourth most populous country with 200 million people where 35% of the population is at risk of malaria. Indonesia was the first developing country to have its own satellite communication system, but it does not currently use this system for malaria information transfer.



Nigeria is the most populated country in Africa with 126 million people. Over 90% of the population in Nigeria lives in malaria-invested areas. The Nigerian Space Agency (NASRDA) is still in its very early stages. The space program is being developed in part to benefit health, education and economic stability. NASRDA does not yet do any malaria mapping.



Kenya has a population of over 30.7 million people where 65% of the population is at risk. Kenya does not have a space program, but it does have a limited space infrastructure that has participated in some malaria mapping initiatives.

While progress in combating malaria has been made, these case studies identified a great need for malaria risk mapping and effective information transfer. A solution that may be effective in India, may not be appropriate in Indonesia or Nigeria or Kenya. HI-STAR is a strategy that could benefit each of these countries. It is part of a global approach that can be customized to meet individual needs.

Implementing the HI-STAR Strategy

While reviewing existing programs, we identified three major constraints that groups may face when seeking to implement HI-STAR. These limitations include cost, lack of resources and lack of technical capability. While these constraints cannot be easily overcome, we will attempt to address them, at least in part, in our implementation strategy. The goal of the HI-STAR strategy is to integrate MIS into existing programs or organizations to maximize resources and capabilities. We suggest a two-phase approach:

1) a development and qualification phase
2) an operational phase

During the development and qualification phase, we recommend space agencies take the lead and develop MIS working closely with the World Health Organization to determine user needs. To develop MIS, space agencies should combine current GIS data with information from existing programs such as CHAART. Once the system is in place, the agencies should obtain regular feedback to ensure the information is relevant.

During the operational phase, we suggest groups such as Roll Back Malaria and the World Health Organization take the lead to ensure specific countries can in fact receive, generate and disseminate information. We therefore recommend that Roll Back Malaria and the World Health Organization operate the system with technical support from space agencies. These groups will need to:

- verify capability and access satellite data
- ensure personnel are trained to input and gather data
- establish infrastructure to disseminate data
- set up processing centers in existing space or health related facilities

HI-STAR seeks to limit costs by depending on existing resources within established organizations.

Costs

The cost of the HI-STAR strategy ranges greatly in conjunction with the specific needs of the individual organization or country. Initial investments are related to the following:

- cost of MIS development
- fee of establishing processing facilities in existing regional centers
- rate for setting up a small coordination center
- expense of developing communications capabilities

We estimate the startup cost of MIS, including information dissemination, in a small country such as Kenya would be about USD $2.5 million. In a large country such as India, which would require a great number of dissemination centers, that number would jump to about USD $14 million. The main cost drivers are the expense of new regional centers, the number of existing dissemination centers and the price of developing communications capabilities in areas where the current infrastructure is insufficient.

Although these costs may appear initially restrictive, the benefits realized by implementing HI-STAR are significant both financially and socially. HI-STAR will ensure a more efficient distribution of limited malaria prevention and treatment resources.

Continuing Fight Against Malaria

Malaria will continue to be a very serious global health problem requiring scientific, technical, institutional and financial solutions. Worldwide incidence of malaria has quadrupled over the past five years and resistance to available drugs is growing rapidly. Malaria prevention is becoming more important than ever.

Space technologies and resources provide malaria early warnings that enable health authorities and policy makers plan their efforts to fight the disease. HI-STAR recommends the increased use of space technology in conjunction with current initiatives. We seek to link the information from space technology to the people who need it most so they can combat vector-borne diseases even more effectively. What would a world without malaria look like?

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1

Introduction

"And I see men become mad and demented from no manifest cause, and at the same time doing many things out of place; and I have known many persons in sleep groaning and crying out, some in a state of suffocation, some jumping up and fleeing out of doors, and deprived of their reason until they awaken, and afterward becoming well and rational as before, although they be pale and weak; and this will happen not once but frequently."

(Hippocrates, 400 B.C.)[1]

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Chapter 1 - Introduction

1.1 HI-STAR

The purpose of this document is to describe a global strategy to integrate the use of space technology in the fight against malaria. Given the well-documented relationship between the vector and its environment, and the ability of existing space technologies to monitor environmental factors, malaria is a strong candidate for the application of space technology.

The concept of a malaria early warning system has been proposed in the past[2] and pilot studies have been conducted[3]. The HI-STAR project (Health Improvement through Space Technologies and Resources) seeks to build on this concept and enhance the space elements of the suggested framework. As such, the mission statement for this International Space University design project has been defined as follows:

"Our mission is to develop and promote a global strategy to help combat malaria using space technology"

The remainder of this chapter provides a general overview of malaria, aspects of how space technology can be useful, and an outline of the HI-STAR strategy.

1.2 History of Malaria

Malaria has plagued humankind throughout history. In Africa, fossils of mosquitoes up to 30 million years old show that the vector for malaria was present. References to malaria can be found as far back as the Vedic writings of 1600 B.C. in India. The first accurate clinical descriptions of malaria were characterized by Hippocrates in 400 B.C[4]. In the seventh century, the Italians named the disease *mala aria,* meaning 'bad air', because of its association with ill smelling vapors from the swamps near Rome[4]. In 1880, the first true sighting of the malaria parasite was made in Algeria by Charles-Louis-Alphonse Laveran, while viewing infected blood under a microscope[5]. However, it wasn't until 1897 that Sir Ronald Ross made the mosquito parasite connection through observations of the malaria parasite in the intestine of mosquitoes[6]. Throughout history malaria has taken a massive toll on human life.

1.3 Malaria Today

Malaria is a vector-borne disease; therefore, it requires an agent, usually an arthropod, to transmit a pathogenic microorganism from an infected individual to another individual[7]. Vector-borne diseases affect almost half of the world's population resulting in high morbidity and mortality[8]. Of the vector-borne diseases that affect humans, malaria, lymphatic filariasis, schistosomiasis and dengue fever are the most common. Though these diseases share some commonalities, each poses diverse challenges for control of the disease. For schistosomiasis and lymphatic filariasis the policy of the World Health Organization is to distribute drugs for treatment. The drugs for these diseases are very effective and as a result, the diseases are under relative control. Conversely, there is no effective treatment for dengue, and because of drug resistance and socio-economic factors, efficient treatment of malaria is complicated. Thus, malaria and dengue are best controlled by taking measures to prevent the disease. Of the four most common vector-borne diseases, malaria is the most common, deadly parasitic disease (Table 1.1). Malaria has been designated as one of the top three infectious diseases in the world by the G8 Summit (2000).

Table 1.1 - Worldwide incidence of most common vector-borne diseases for 2000[9]

	Population at risk	Infections/yr	Deaths/yr
Malaria	2,100,000,000	300,000,000	1,090,000
Schistosomiasis	600,000,000	200,000,000	14,000
Lymphatic filariasis	1,100,000,000	120,000,000	0
Dengue fever	2,500,000,000	50,000,000	24,000

Over 40% of the world's population is at risk of malaria infection. Malaria causes more than 300 million infections and over 1 million deaths worldwide every year[10]. The disease exists in over 100 countries and is endemic in 90 countries. Over 90% of all malaria cases occur in Sub-Saharan Africa. Malaria is both a cause of poverty and a result of poverty. The disease has significant direct and indirect costs, which have been shown to be a major constraint to economic, political and social development in developing countries[11].

Recently, there have been an alarming number of malaria outbreaks and a general resurgence of the disease[12,13]. In addition, the risk of emergence of malaria in developed countries is on the rise. This trend is thought to be a result of changes in public health policy, growing insecticide and drug resistance, a shift in emphasis from prevention to emergency response, demographic and societal changes, and genetic changes in pathogens[9]. In addition, global climate changes both in the short term, (for example: El Niño, La Niña) and the long term (*i.e.* global warming), may also be associated with a resurgence of malaria[14].

There is not one single solution to solve the malaria problem. Malaria is a complex, multifaceted disease that requires a combination of scientific, technical, medical, institutional and financial inputs to combat its effects. In general, there are two approaches to combating the disease: prevention and treatment. Prevention measures can help reduce the spread of the disease, leading to a decrease in infection and therefore reducing treatment requirements and loss of life. Timely detection of malaria danger zones is essential to help health authorities and policy makers determine how to handle malaria resources. Danger zones can be determined by exploiting the relationship of malaria and various ecological and climate features, which are distinct indicators of mosquito breeding sites. The combination of these environmental and epidemiological features provide key data for advanced warning of malaria outbreaks.

1.4 Why Space?

Space technology provides a supportive approach to the study of environmental indicators of malaria. Space technologies useful for fighting malaria include; remote sensing (RS), Global Navigation Satellite Systems (GNSS) and satellite telecommunications. When used with Geographic Information Systems (GIS), remote sensing data can be utilized to monitor the distribution, dynamics, and environmental correlates of malaria. Remote sensing involves gathering digital information about the Earth's surface from airborne or satellite platforms and transforming them into malaria risk maps. GIS is a data management system that organizes and displays digital map data from RS or other sources. It facilitates the analysis of relationships between mapped features in order to monitor the incidence of malaria and predict outbreaks. GNSS can support accurate mapping, such as localization of malaria cases, as well as positioning of infrastructure. Satellite telecommunications are useful in combating malaria because they provide a system to facilitate the collection and transfer of GIS data as well as a means to disseminate risk maps and epidemic warnings to the proper personnel. In addition, satellite telecommunications can provide a vehicle for the education of health care professionals and potential sufferers.

1.5 Global Strategy

It is clear that malaria is "a global problem in need of concerted effort at a global scale"[15]. Our global strategy is designed to assist in the fight against malaria by using space technologies. The main component of this strategy is the Malaria Information System (MIS), which is a combination of remote sensing and GIS technologies designed to gather critical data about the distribution of malaria and produce risk maps (Figure 1.1). The other components of this strategy utilize space telecommunications to distribute appropriate information to health officials and local authorities in a timely manner. The global strategy does not attempt to replace existing malaria programs; it is designed to support and be integrated with existing programs. In our strategy, the information obtained from the Malaria Information System would complement current prevention initiatives by providing early warning of malaria epidemics. In addition, the global strategy is a flexible system that can be adapted for specific regions and environmental parameters.

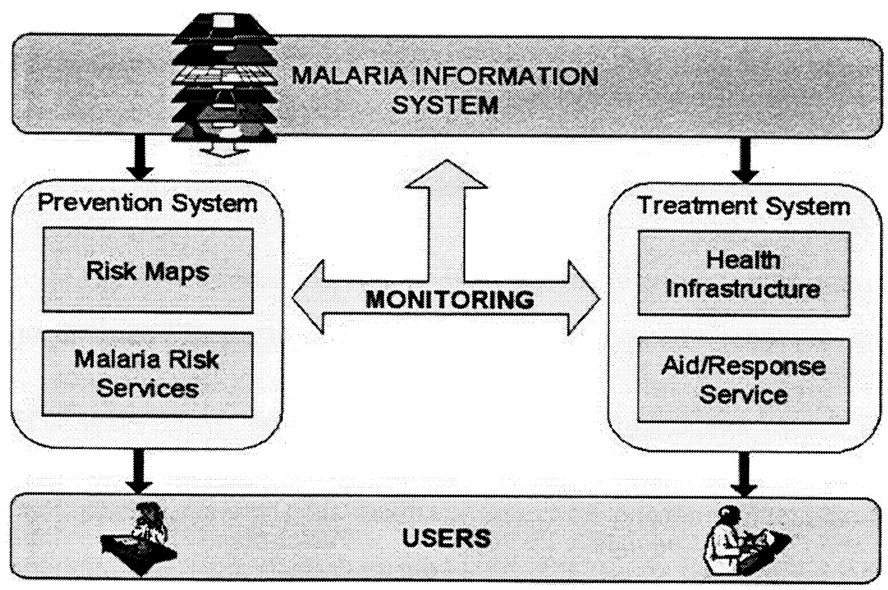

Figure 1.1 – Illustration of Proposed Strategy

1.6 Project Approach

To design our global strategy, the HI-STAR team–

- presents malaria research describing its basic characteristics, associated environmental parameters, and emerging global trends;
- reviews the important space technologies that are effective eco-epidemiology tools against malaria;
- introduces the concept of the Malaria Information System (MIS), describes its possible technical structure and output, users, added value and presents a system cost estimation;
- considers potential scenarios for MIS output dissemination, examines opportunities and challenges for establishing a dissemination system in developing countries, taking into account political, economic and social aspects;
- conducts a review of current malaria programs/initiatives, analyzes program needs and constraints, and describes an implementation strategy, promotion and funding policies for ;its development and operation;
- examines four nations (Kenya, Nigeria, India and Indonesia), in order to assess their existing malaria programs, space infrastructure and present a cost-benefit analysis and implementation strategy for using this global strategy; and
- provides conclusions which include benefits, constraints and recommendations.

1.7 References

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2

The Case of Malaria

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Chapter 2 - The Case of Malaria

2.1 Introduction

Malaria kills roughly twice as many people worldwide as AIDS, and drugs no longer are effective in treating many strains. Mosquitoes in diverse parts of the world now carry the disease, which is transmitted all over the world. This chapter gives a description of the disease, how it is transmitted, where it is found and its impact on the world covering social, economic and political aspects. Prevention and treatment methods are described as well as the close connection between malaria occurrence and environmental factors, known as eco-epidemiology, is treated.

2.2 Malaria: A Complex and Deadly Disease

Malaria parasites undergo a complex life cycle alternating between humans and *Anopheles* mosquitoes. The parasite could not complete its lifecycle without one or the other. The disease is caused by four species of parasites, which thrive in the tropics and sub-tropics; *Plasmodium falciparum, P. malariae, P. ovale,* and *P. vivax*. Various strains may exist within well-defined species, depending on biological variations from one geographical area to another. *Plasmodium falciparum* is the most common and deadly accounting for 95% of all deaths[1].

Figure 2.1 represents the life cycle of *P. falciparum*. Different stages of the cycle are labeled and together they illustrate the 'two bite' process of malaria infection.

1. *Plasmodium facliparum* enter the human body when an infected *Anopheles* mosquito takes a blood meal.
2. Once inside the human host, *Plasmodium* sporozoites enter the cells of the liver where they reproduce asexually forming merozoites.
3. After 9-16 days the liver cells burst releasing the merozoites into the blood.
4. They penetrate the red blood cells, where they multiply again, progressively breaking down the hemoglobin. The red blood cells then burst (resulting in fever).
5. Some parasites differentiate into the sexual stages, called gametocytes.
6. A mosquito can subsequently ingest these cells during a blood meal.
7. In the mosquito, the gametocytes join in the gut where they transform and eventually release thousands of sporozoites. The sporozoites invade the mosquitoes salivary glands, thus restarting the cycle[2]

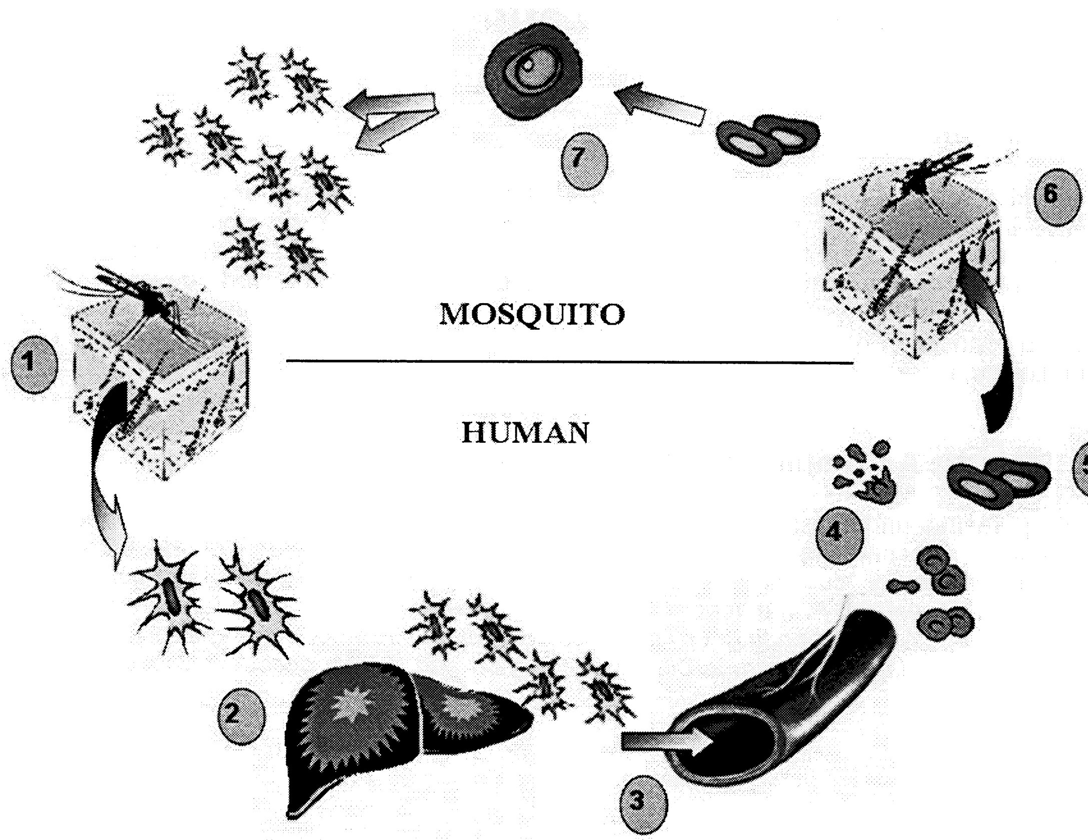


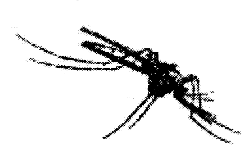
Figure 2.1 - Life Cycle of *Plasmodium falciparum*
(Courtesy of A. Jennings)

Only the female *Anopheles* mosquitoes can transmit malaria, as the males do not feed on blood. Out of the 380 species of *Anopheles* mosquitoes, there are only 60 that can transmit malaria[3]. The life cycle of the *Anopheles* mosquito consists of four different stages; egg, larva, pupa and adult mosquito. The adult female *Anopheline* requires a blood meal (approximately every two or three days) in order to produce eggs. The eggs are laid on stagnant water in batches of about 100-150. Female mosquitoes continue to lay eggs throughout their life span of approximately 2 to 3 weeks[4]. Two to three days after the eggs are laid mosquito larvae emerge and feed on small organisms and plants in the water, and grow to become a pupa. The pupa remains in the water but does not feed. After 2 to 3 days the adult mosquitoes will emerge from the pupa and take flight. Mating soon follows, after which the female, who mates only once, normally takes her first blood meal. Then the female develops her first batch of eggs, recommencing the cycle[2]. Malaria is not passed on to the eggs. In tropical countries it takes 7-14 days for a mosquito to grow from an egg to an adult mosquito[5].

In general the mosquitoes that transmit malaria to humans breed within 2 kilometers of human habitation. Most Anopheles mosquitoes bite during the night or at sunset. After biting, mosquitoes usually rest for a short period.

Once bitten by a malaria-carrying mosquito, the first symptoms of infection transpire 9-14 days after contact with the vector[4].

The *Anopheles* mosquito can be recognized by its upturned tail



At first symptoms are flu-like; fever with or without other indications such as headache, muscular aches and weakness, vomiting, diarrhea and coughing. The periodicity of fever cycles coincides with parasite multiplication and destruction of red blood cells. This

destruction causes acute anemia which further compromises health. Death may result from clogged blood vessels that supply the brain (cerebral malaria) or other vital organs[2].

Malaria exists in two main forms. Either it is prevalent in a particular locality, region or population, that is to say endemic; or malaria is epidemic and appears more in the form of an outbreak that spreads rapidly and widely in the population. Endemicity is characterized by continuous presence, low contagion speed and a relatively small amount of affected people. In endemic areas, part of the population survives the disease and develops high levels of immunity early in life. Vulnerable people in these areas are thus limited to young children or adults coming from other areas. Different levels of endemicity (holo-, hyper-, meso- and hypoendemic) are distinguished. Epidemicity is linked to the number of vulnerable people, who are likely to catch the infection if exposed to it. Variability in time and space, high contagion speed and a high number of affected people are other characteristics of epidemicity[2,6].

2.3 Malaria: A Widely Spread Disease

Malaria occurs in many locations of the tropical world and in some locations of the subtropics. It is most common between the latitudes of 23.5° North (Tropic of Cancer) and 23.5° South (Tropic of Capricorn) but cases also occur outside of these latitudes in areas such as portions of South Africa (Kruger National Park and surrounding area - 25° South) and New Delhi, India (28.5° North)[7]. Figure 2.2 shows the distribution of malaria in the world[8].

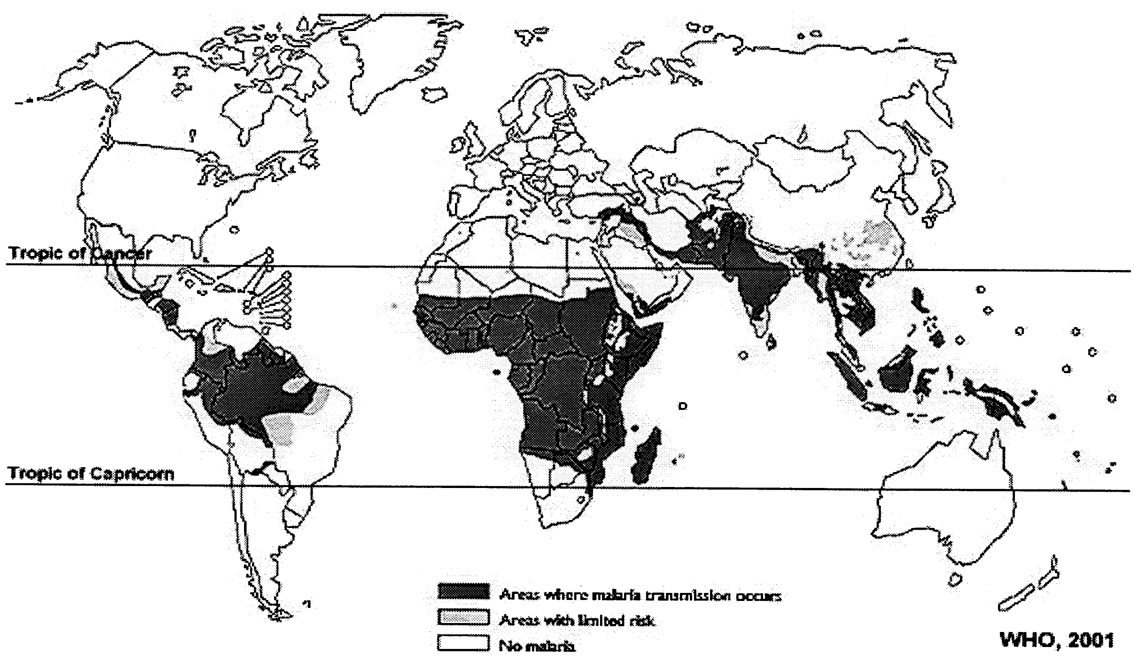


Figure 2.2 - Distribution of Malaria (World Health Organization, 2001)

Over the past 10 years, the geographical distribution of malaria has been spreading to Northern areas. There has been reinvasion of malaria for example in areas of northern India, Turkey, and Russia, as well as occasional outbreaks in Europe and North America. Malaria transmission is possible if the weather conditions are right to support the growth and infection of *Anopheles* mosquitoes and if a reservoir of malaria parasites is available, *Anopheles* mosquitoes exist in many northern areas, including the U.S. and Europe. The malaria parasite reservoir becomes available in non-malarious regions when people arrive with malaria from malaria endemic countries. Malaria transmission can occur if an *Anopheles* mosquito becomes infected by biting a person with malaria, and then later bites an uninfected

person. Malaria transmission in developed countries has also been traced directly to airplanes or ships carrying infected *Anopheles* mosquitoes[9].

2.4 Malaria: A Burden for the World

People suffering from malaria have to cope with a severe and potentially deadly infection. Treatment is costly and care requires a lot of effort. As a result of the high number of infected people, especially in malaria-endemic countries, malaria leads to numerous direct and indirect effects on a large scale. These include social, economic and political dimensions. The following sections describe the main consequences of malaria both for developing and for developed countries.

2.4.1 Social, Economic and Political Impacts for Developing Countries

Malaria poses heavy burdens on the people, economies and governments of the developing countries that are at risk. At a personal level, families have to cope with deaths or have to take care of sick and weak family members. Sickness or even death of the main provider of income has strong negative implications for the family.

Children cannot attend school because they may need to take over the work of sick parents. In some areas of the world up to 28% of school-absenteeism can be attributed to malaria[10]. This indirect or second-order effect reduces the opportunities of education for the children, which again affects the future wealth of the family as well as the economy and the development of the affected country as a whole. Another important indirect effect is a high birth rate because parents risk losing children through malaria. This also affects the available income and the chances for education for children.

In economic terms the loss of workforce slows down economic activity and reduces productivity. WHO estimates that the Gross National Product of countries in Africa is reduced by up to 1.3% because of malaria[11]. Some affected families will have problems handling the harvest and external investments may seem inappropriate with an uncertain future. In addition, potential foreign investors refrain from investing in malaria-affected countries because of the risks. As a result, technical and economic developments are slowed, increasing the gap between developed and developing countries[12].

The effects of malaria on the political systems of developing countries are diverse. First, the public health system is heavily occupied by a large number of malaria cases, causing other medical expenditures or investments in *e.g.* education or infrastructure to suffer. Even programs aimed at water supply, sanitation infrastructure or agriculture sector may be affected. Second, the economic effects on private businesses mentioned above reduce the tax revenues of the government, further narrowing its options of activities. An overall delay of development is highly likely, because the government is partly blocked by having to cope with negative effects of malaria on a large scale.

2.4.2 Social, Economic and Political Impacts for Developed Countries

The actual effects of malaria on developed countries can be roughly divided into the direct risk of people in developed countries to be infected with malaria and the indirect effects that influence the political or economic situation. Malaria is not endemic in any developed country, however Europe and the United States have had recent malaria outbreaks. In 1996, approximately 10,000 reported cases of malaria were imported into the European Community, with one fourth of them reported from the United Kingdom[13], and 1000 to 1200 cases annually have been reported recently in the United States. The Center for Disease Control and Prevention estimates that cases reported in the US represent only about half the actual incidence.

"Every year approximately 7 million tourists and business people spend time in regions where malaria is endemic, as do military personnel and foreign visitors to the United States and it is

likely that thousands arrive here with malaria parasites in their body. As a consequence, locally transmitted malaria, absent from the United States for almost 30 years, has returned"[14]

The continuously high numbers of malaria cases and deaths that lead to heavy burdens on developing countries also affect developed countries through economic and political links across the globe. A WHO study investigated the potential economic development in sub-Saharan countries during the last 35 years. The researchers estimated that if the GDP of these countries were higher, their need for aid could be reduced from the current level of 20 billion USD per year[14].

The suppressed or delayed development of countries strongly affected by malaria increases the difference in living standards between these countries and the developed ones. Many international organizations, including the WHO, invest heavily towards the eradication of malaria through increasing aid; money that could be used for other purposes such as development and cooperation.

2.5 Current Prevention and Treatments

2.5.1 Malaria Prevention

Prevention of malaria encompasses a variety of measures that may protect against infection or against the development of disease in infected individuals. Measures that protect against infection are directed against the mosquito vector. These can be personal (individual or household) protection measures *e.g.* protective clothing, repellents, bed nets, or community/population protection measures *e.g.* use of insecticides or environmental management to control transmission. For example, Insecticide Treated Nets (ITNs) are very effective. Studies across Africa have revealed that malarial cases among children that sleep under nets are reduced by 50 percent[15].

Measures for protecting against the disease, without preventing infection, include immunization (still at experimental stage) and chemoprophylaxis. Malaria vector control measures are noted to be sufficient to eliminate the *Anopheles* population or reduce it below the number required to sustain disease transmission. Three main methods are used to reduce mosquito populations[16]:

1) Biological control: Several methods of biological control currently exist. One involves the introduction of *Bacillus thuringiensis israelensis*, a mosquito bacterial pathogen, into a targeted mosquito population. Another requires the introduction of mosquito larvae-eating fish, *Gambusia spp.*, into breeding areas.
2) Elimination of breeding sites: Aside from limiting water containers in bivouac areas or simple ditching to provide drainage, permanent removal of breeding sites requires careful and thorough engineering, heavy equipment, and personnel.
3) Insecticides consist of three main types:
    a. Chemical control of larvae. Treatment of standing water with larvicides provides temporary control of mosquitoes and is more effective than adult control techniques.
    b. Chemical control of adult mosquitoes. The treatment of choice to control adult mosquitoes is ultra-low-volume spraying (ULV). ULV insecticides must be applied on a repetitive schedule, typically twice daily, daily, or every other day.
    c. Chemical control of adult mosquitoes (Barrier Treatments). Residual spray treatment of all vegetation surfaces within 30 meters of small camps or bivouac areas can establish a barrier against mosquito re-infestation.

The majority of national malaria policies particularly within African countries stress the disease prevention mechanisms rather than treatment options. But the application of disease prevention methods currently faces a number of interrelated problems and obstacles, the most important being:

1) Outmoded managerial practices and administrative problems.
2) Lack of funds.
3) Lack of qualified staff.
4) Lack of guidance in the selection of appropriate methods.
5) Disregard of data from sectors outside the malaria services as for example meteorological, agricultural and development etc.

2.5.2 Malaria Treatments and Drug Resistance

Adequate treatment of malaria is becoming increasingly difficult because of worsening problems of drug resistance in many parts of the world. Although some new drugs have appeared in the last 20 years (*e.g.* mefloquine, halofantrine, artemisinin derivatives, malarone, atovaquone and proguanil, co-artemether), there is an urgent need for new - especially inexpensive - drugs and more practical formulations of existing drugs and compounds.

In Africa for example, with increasing levels of chloroquine resistance and fears of toxicity and decreased efficiency for sulfadoxine/pyrimithamine, an affordable, effective and safe alternative to chloroquine is needed. Malaria experts are now recommending changing the treatment protocols to include a combination of drugs.

An effective vaccine would constitute a powerful addition to malaria control. More than a dozen candidate vaccines are currently in development, or in clinical trials. The hope is that an effective vaccine will be available within the next 7-15 years[17].

In spite of drug resistance, malaria is a curable disease, not an inevitable burden. Although only a limited number of drugs can be used, if these are used properly and targeted to those at greatest risk, malaria disease and deaths can be reduced, as has been shown in many countries[18].

2.6 Malaria and the Environment

2.6.1 Habitat Characteristics

The *Anopheles* mosquitoes normally breed in water pools and usually live in an area of about 1 to 2 km around their breeding sites. They occur in relatively discrete patches where the habitat and the climate are favorable. Mosquitoes acquire the disease organism when feeding on an infected host and pass it to another host during a subsequent blood meal. The time taken for the malaria parasite to develop in the mosquito is temperature dependent, usually 10 to 17 days. The following are general habitat characteristics of Anopheles[19,20]:

1) Breeding habitat

   Mosquito eggs are deposited in water. The favorable type of water and vegetation in the water varies between species. Preferred sites include small containers, edges of reservoirs, sunlit rain-pools, irrigation ditches, shaded water and dirty water (Figure 2.3). Depending on species, female mosquitoes may lay 100 to 150 eggs at a time and may average 1,000 to 3,000 during their lifespan.

   Eggs hatch within days and the aquatic larvae feed on microorganisms. The larval stage of all tropical mosquitoes lasts 5 to 10 days. The pupa stage lasts for 1 to 2 days.

Figure 2.3 - Breeding sites of mosquitoes[21]

2) Feeding habitat

   Only female mosquitoes bite in order to get proteins from a blood meal to produce eggs. Feeding habitats are considerably different between species with respect to time, place and host preference. Malaria does not have animal reservoirs and thus, only mosquitoes with a high preference for human blood are important for disease transmission. Mosquitoes can find new hosts by sight, by detecting infrared radiation emitted by warm bodies and by chemical signals such as existence of CO_2.

3) Resting habitat

   Most mosquito species are either nocturnal or crepuscular and remain relatively inactive during the daylight hours. Natural resting sites for mosquitoes include dense vegetation, animal burrows, caves and tree holes. Basements, stables, chicken coops and culverts are examples of man-made structures that can harbor large diurnal populations of resting mosquitoes.

4) Flight range

   The flight range of this species varies and depends to some extent on the number of adults produced within a given area and the proximity to suitable hosts. Although a few species may range up to 30km or more, most mosquitoes remain within 1 to 2 km of their breeding site. These flights are individual, rather than in swarms.

5) Longevity

The average life span of the female mosquito is 3 to 100 days, whereas the male's is 10 to 20 days. Depending on temperature, mosquitoes can develop from egg to adult in as little as 4 to 7 days. Standing water that has stagnated for more than 3 days enhances numbers of adult mosquitoes.

2.6.2 Environmental Parameters

Some environmental parameters are closely related to the mosquito habitats and in particular the mosquito breeding habitat. For example the mosquitoes cannot survive in low humidity. Rainfall expands breeding grounds, and in many tropical areas, malaria cases increase during the rainy season. Malaria parasites are affected by temperature, and their development slows as the temperature drops. Those factors cause current geographical distributions of malaria.

The main ecological parameters for malaria distribution are the following [22]:

1) *Rainfall*
Rainfall provides the breeding sites for mosquitoes and increases humidity necessary for mosquito survival. If the soil is not too porous, plentiful rainfall will create many rain-pools that support breeding habitat of malaria. If an area has distinct dry and wet seasons, both mosquito density and disease prevalence are likely to have seasonal patterns.

2) *Soil type*
If soil is compacted, ground cover is removed or soil is exposed to excessively dry conditions, soil loses its permeability or porosity and rain-pools last longer. Impermeable soil allows water stagnation and creates grounds for mosquito breeding.

3) *Soil Moisture*
Wet soils indicate a suitable habitat for species of mosquito larvae.

4) *Surface water / Flooded areas*
Water pools are strongly related to mosquito breeding habitats. Mosquitoes rarely occur in deep water pools like lakes and large ponds or in steep current rivers, except at shallow margins. Flooded areas that produce a lot of non-flow pools play an important role of outbreak of malaria transmission.

5) *Humidity*
Low humidity makes lifespan of mosquitoes shorter, leading to a reduction of transmission of the disease. Mean relative humidity of 60% is adequate for malaria.

6) *Vegetation type*
Tropical rain forest vegetation and shaded or partly shaded margins of forest pools and streams make *Anopheles* mosquitoes abundant. Emergent or floating vegetation in deep water creates vector-breeding sites.

7) *Deforestation*
Forest clearance is a problem since it provides the vector with additional open sunlit pools for breeding

8) *Temperature*
Low temperature prevents parasite and vector development. High temperature increases mortality of the vector. 22-32 degrees C is adequate for malaria[23].

9) *Altitude*
The habitat of malaria depends indirectly upon altitude since elevation affects temperature and humidity. Further, different vector species establish their population at different heights.

2.6.3 Eco-epidemiology, New trends, and Translocation of the Species

The recent resurgence of infectious diseases has been correlated with new technologies in production, transportation and human population increases which are transforming ecological systems on a global scale. Research into the control of vector-borne diseases has now broadened to include the study of the impacts of environmental changes or "eco-epidemiology"[24].

Mosquito breeding is profoundly affected by rainfall and therefore climate plays a major role in malaria transmission. The most common factor in malaria epidemics is, however, abnormal meteorological conditions, which temporarily change the ecological equilibrium between host, vector and parasite. Rainfall alone may not be a good indicator of malaria transmission risk in warm semi-arid areas. Its impact on the local ecology is governed by hydrological process associated with topography and soil type. In addition, the drainage basin changes as a result of flowing water as well as human activities. For instance, epidemics may arise following the development of dams or irrigation schemes, which change the local environment and, consequently, the previous ecological equilibrium. In such a situation a disaster warning system based on the water levels in rivers or dams may be very valuable – as has been proposed for the Senegalese river basin[25].

Areas of drought are also of interest as 2-3 years of drought can reduce the normal level of immunity in a population (accompanied with malnutrition). Considering the weather and environmental monitoring (when used in combination with archived data), areas with excess rainfall and low immunity can then be picked out and the authorities can be alerted of the potential of a malaria epidemic.

Many malaria vectors respond sharply to changes in the ecology of their habitat; deforestation, vegetation, density of human population, bodies of water and their locations and climate. Upsurges of malaria have been associated with changes in land-use and human settlement subsequent to deforestation in Africa, Asia, and Latin America. Also new populations or resettled populations from other regions may lack familiarity in dealing with a newly deforested region's environment and engage in practices leading to their becoming infected, and in turn, become reservoirs of infection, rapidly leading to an increased incidence of malaria[26].

Ecological studies of agent-vector-host relationships and improved surveillance methods have been cited as important priorities to help address vector-borne diseases such as malaria. As a result geographic information systems are playing an important role in viewing the problem of malaria at a variety of geographic scales, which has led to improved understanding of the disease process[28].

2.6.4 Effect of Global Climate Changes

Reference to global warming refers to the long-term effects of upward trends in global temperatures that climatologists have predicted will occur by the end of the 21st century. As global warming continues, there is some concern that this may increase the transmission of vector-borne diseases like malaria and potential for their movement into temperate regions (although noted to be debatable)[30].

However a recent study published in *Nature*[27], noted that climate change was not responsible for changes in malaria cases in four regions of Africa, where the disease has increased fivefold in the past two decades. The research team reconstructed climate in these regions between 1911 and 1995 and chose upland areas because they are the most sensitive to climate change. The climate reconstruction revealed no significant trends in temperature, rainfall or the number of months when conditions were suitable for malaria transmission. Malaria thrives in warm, wet, weather, but the climate had not changed and was not responsible for changes in malaria. Resultantly, the authors caution about drawing simplistic links between global warming and local disease patterns.

Shorter-term climate events like the El Niño Southern Oscillation (ENSO) have been investigated to study the dynamics of vector-borne disease transmission. The ENSO phenomenon is second only to seasonal variability as the strongest driver of weather variability in many regions of the world. For example in the East African highlands, El Niño results in excessive rainfall and in southern Africa, drought. Surveillance systems need to be developed in order to identify associations between climatic phenomena and locally appropriate indicators of outbreaks of malaria[31]. Researchers in Colombia noted that the El Niño phenomenon intensified the annual cycle of malaria cases in endemic areas of Colombia as a consequence of anomalies in the normal annual cycle of temperature and precipitation. During normal years, endemic malaria in rural Colombia exhibited a clear-cut normal annual cycle, which was associated with mean temperature, precipitation, dew point and river discharges. During historical El Niño events (interannual time scale), the timing of malaria outbreaks did not change from the annual cycle, but the number of cases intensified. This was associated with an increase in mean temperature, decreases in precipitation, increases in dew point, and decreases in river discharges, all of which favor malaria transmission[28].

Increases in malaria cases cannot be attributed to climate trends alone. Although vector populations are sensitive to climate trends, there are multiple other factors such as drug resistance, housing conditions, public health resources, and access to medical care, which are more likely to influence the emergence of vector-borne diseases, (even in areas where the core temperature may be increasing in response to climate change)[28].

2.7 Conclusion

Malaria will continue to be a very serious global health problem that will require scientific, technical and financial assistance from the resource-wealthy developed world (WHO, 1998). Worldwide incidence of malaria has quadrupled in the past five years, and resistance to available drugs for prevention and treatment is growing rapidly. Nearly 40% of the world's population lives in regions where malaria is endemic and millions more live in areas that are encountering the disease for the first time in decades[17].

WHO's global strategy includes strengthening of local research capacities to promote regular assessment of countries' malaria situations, in particular the ecological, social and economic determinants of the disease. Ecological studies of agent-vector-host relationships and improved surveillance have been cited as important priorities for assessing the global spread of malaria[28].

Environmental parameters such as temperature, humidity, altitude, rainfall, and soil, are important factors in the rate of spread of the disease, yet long term climate changes, such as global warming are inconclusive (in regards to how this will effect malaria transmission)[26]. Ecological studies of agent-vector-host relationships and improved surveillance methods have been cited as important priorities by the World Health Organization and Public Health experts in order to broaden the assessment of environmental factors that are related to the spread of malaria. This "eco-epidemiological" approach is emerging due to worldwide changes in the transformation of ecological systems[29].

Remotely sensed data can be used to detect and map environmental variables that are related to the spread of malaria in order to prevent and forecast epidemics. This information could be useful to local health ministries at the district level in order to plan for impacts on the health care system. Remote sensing and other related space technologies will be treated in the following chapters.

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Space Technology: An Effective Tool for Eco-epidemiology

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Chapter 3 – Space Technology: An Effective Tool for Eco-epidemiology

3.1 Introduction

As explained in Chapter 2, the endemic and epidemic malaria characteristics are closely related to environment. Prevention of malaria relies upon the ability either to detect the main characteristics of the habitat and environment of mosquitoes or to detect the *Anopheles* mosquitoes directly. The present chapter will show how remote sensing can help to monitor most of the ecological parameters involved in the distribution of malaria. However, the knowledge of the ecological parameters is not sufficient for accurate predictions and monitoring of malaria and epidemiological data are often necessary. For example, the number and location of malaria cases can be valuable information. In all cases, Chapter 3 will show how space technology can help gathering reliable ecological and epidemiological data using remote sensing, Global Navigation Satellite Systems or telecommunication satellites.

3.2 Remote Sensing

3.2.1 Introduction to Remote Sensing

Remote sensing involves gathering image information about features of the Earth's surface from satellites and aircraft. These systems carry different types of active and passive sensors. A 'passive' system generally consists of an array of small sensors or detectors which record the amount of electromagnetic radiation reflected and/or emitted from the Earth's surface. A camera is an example of a passive system. An "active" system propagates its own electromagnetic radiation and measures the intensity of the return signal. Radar is an example of an active system. Aircraft may carry a Light Detection And Ranging (LIDAR) instrument that receives reflected pulses of a laser used to create a terrain model of the surface.

Remotely sensed data acquired by the Earth observation satellites provide a number of benefits for studies of the planet surface, including:

- Up to date image information based on regular revisits
- Ability to perform retrospective analysis
- Large area coverage
- Accessibility to difficult areas
- Good spectral, spatial and temporal resolution
- Compatibility with new digital technologies
- Ability to manipulate and enhance image data
- Fast acquisition compared to aircraft remote sensing

In general, the applications of Remote Sensing include:

- assessment and monitoring of vegetation types and their status
- soil surveys
- mineral exploration,
- map creation and revision, production of thematic maps
- water resources planning and monitoring
- urban planning
- agricultural property management planning
- crop yield assessment
- natural disaster assessment, *etc.*

Information derived from remote sensing data is most valuable when used in conjunction with other additional data (*e.g.* soils, elevation, slope, aspect, depth to ground water). Satellite images form one of the most important sources of data. Prior to analysis, digital images usually require some degree of pre-processing including geo-correction, registering, filtering, radiometric and geometric corrections and also enhancement, in order to become useful inputs[1]. Many remote sensing projects do not require detailed radiometric correction. However, projects dealing with water quality, differentially illuminated mountainous terrain, differences in vegetation health, biomass, and leaf area index especially require careful radiometric correction[2].

3.2.2 Mapping of the Ecological Parameters for Malaria Distribution

As described in Chapter 2, the main ecological parameters used for monitoring or prediction of malaria distribution are the following:

- Soil type & soil moisture
- Surface water & flooded areas
- Vegetation type & deforestation
- Climate (*e.g.* temperature, humidity, rainfall)

Since the launch of the first remote sensing satellite Landsat 1 in 1972, several satellites and missions have offered different possibilities for Earth Observation studies. The opportunities offered by remote sensing to map the ecological parameters related to malaria distribution are discussed below.

3.2.2.1 Vegetation Type and Deforestation

As mentioned above, mosquitoes have a favorable vegetation environment. Some of these factors can be detected from space. Different types of vegetation, crops, soil and urban areas all exhibits different characteristics in absorption and emission spectra that can be detected by remote sensing. Several wavelength bands of the electromagnetic spectrum are used to distinguish the different land covers. For example, crop types can be differentiated using the visible (VIS) Near Infrared (NIR) and Mid IR bands. The majority of current vegetation maps are based on data with 20-30m spatial resolution. Nowadays multi-spectra images with spatial resolution down to a few meters (2.5m QuikBird) are available. For high temporal resolutions, satellites that cover larger areas are used. The Advanced Very High Resolution Radiometer (AVHRR) sensor has a 1.1km spatial resolution and can map vegetation for large regions. The vegetation 'green-up' is most commonly calculated and monitored by the

Normalized Differential Vegetation Index (NDVI). It describes the chlorophyll activity of the vegetation, which is dependent on the rainfall, temperature and humidity. Therefore the NDVI can give an idea of the state of the vegetation related for example to seasonal changes.

Land cover maps have been made since Landsat 1 became operational thirty years ago. Wood *et. al.* used Landsat 5 with a Geographic Information System (GIS) to successfully identify high mosquito producing rice fields in California. A recent proposal for a malaria early warning system[3] suggests the use of NDVI data with a spatial resolution of 1.1km generated by merging 10 days data from NOAA images.

Among the ecological parameters considered in this section, deforestation is one of the most common changes in land cover and can make the breeding conditions more favorable to the mosquitoes. Therefore, deforestation is an important ecological parameter to monitor. To do this, high-resolution images such as those from Landsat, Spot, Ikonos, QuikBird and Radarsat, are needed. The use of SAR type sensors is an advantage because they can be used independent of cloud cover.

3.2.2.2 Soil Type and Soil Moisture

Recent advances in remote sensing have shown that soil moisture can be measured by a variety of techniques including synthetic aperture radars (SARs), short-wave-infrared, and thermal-infrared sensors[4].

However, only microwave technology has demonstrated a quantitative ability to measure soil moisture under a variety of topographic and vegetation cover conditions so that it could be extended to routine measurements from a satellite system. SARs are particularly important for sensing ground conditions in areas of cloud cover or vegetation canopy cover.

Currently, the European Remote Sensing satellite (ERS) C-band and Envisat-1, the Japanese Earth Resources Satellite (JERS) L-band and the Canadian RADARSAT (also C-band) SARs are operational. It has been demonstrated that an L-band system would be optimum for measuring soil moisture.

Table 3.1 shows the available sensors that can be used for mapping wetlands and deriving soil moisture. The SAR-C, SAR-L, Short-Wave Infrared and Visible-Near-Infrared spectral bands are mostly used to study wetlands. Soil moisture identification is based on the SAR-C, SAR-L, Short-Wave Infrared and the Thermal Infrared spectral bands. The table covers several spatial and temporal resolutions.

Several studies using SAR data were conducted to monitor wetlands and soil moisture as input for identifying suitable environmental factors related to malaria. Kaya *et al.*[1] used RADARSAT data to demonstrate the SAR's ability to target moisture conditions for disease monitoring applications. However, one big drawback to the existing SAR systems in the applications related to soil moisture is the limitation caused their low temporal resolution (see Table 3.1).

Table 3.1 - Current sensors for monitoring and mapping wetlands and soil moisture[5]

Temporal resolution	***Spatial resolution***		
	High (10-30m)	*Medium (30-200m)*	*Low (0.5-5km)*
< 2 days			NOAA, SPOT4-Vegetation, Terra-MODIS
5-16 days	SPOT-HRVIR, Terr-ASTER, Landsat-TM, Landsat-ETM+, Radarsat	IRS P3 WIFS, Landsat-TM, Landsat-ETM+, Radarsat, Resurs-O1	Terra MISR
16-35 days	IRS-1A LISS II, IRS-1B LISS II, IRS-1C LISS III. IRS-1D LISS III, ERS-2 AMI-SAR, CBERS CCD, Envisat1-ASAR	IRS-1A LISS I, IRS-1B LISS I, IRS-1C LISS III. IRS-1D LISS III, ERS-2 AMI-SAR IRS-1C WiFS, IRS-1D WiFS, CBERS IR-MSS	ERS-2 ATSR-1, Envisat1- AATSR,

3.2.2.3 Surface Water and Flooded Areas

Chapter 2 describes water bodies in terms of stagnant water, irrigation canals and flooded areas, all of which encourage mosquito breeding and survival. Nowadays, remote sensing technology regularly provides data on stagnant water areas and maps flooding zones by using optical and also radar sensors.

Optical sensors are very helpful for mapping surface water and flooded areas. To map irrigating canals, very high-resolution sensors are required. Radar sensors can be used to monitor land flooded areas and flooded forests using subsidiary and interferometry techniques. Table 3.2 below describes which sensors are used for mapping flooded areas, water canals and stagnant water.

Table 3.2 - Current Sensors for Monitoring and Mapping Water Bodies[6]

	Temporal resolution	*Spatial resolution*		
		Very High (<5m)	*High (10-30m)*	*Medium (30-200m)*
Flooding, stagnant water	5-35 days		Landsat-TM, Lansat-ETM+, Terra-ASTER, Spot-HRVIR, CBERS-CCD, IRS-1C-LISSIII, ERS-AMI-SAR, IRS-1A(1B)-LISSII, Radarsat	IRS-1C-LISSIII, IRS-1D-LISSIII, IRS-1A-LISSI, IRS-1B-LISS1, Radarsat
Canals	5-35 days	Ikonos, Quikbird	Landsat-TM, Lansat-ETM+, Terra-ASTER, Spot-HRVIR, CBERS-CCD, IRS-1C-LISSIII, ERS-AMI-SAR, IRS-1A(1B)-LISSII, Radarsat	
Flooded Forests	5-35 days		ERS-AMI-SAR, Radarsat	

3.2.2.4 Climate

Temperature, humidity, wind and precipitation are well known as the main climatic factors that affect and predict malaria transmission. Related changes in these environmental factors and the El Niño Southern Oscillation may alter the quality and availability of some vector breeding sites. Climate changes are expected to influence malaria directly by modifying the behavior and geographical distribution of malaria vectors and by changing the length of the life cycle of the parasite. Indirect effects of climate changes may also alter the relationships between the vector, parasite, and host involved in malaria transmission.

Meteorological data gathered from different ground sensors are not uniform and therefore limit their use for modeling of diseases. Remote sensing technology provides data to monitor climate change directly or using models. Remote sensing satellites can also measure meteorological parameters such as atmospheric temperature, humidity, and surface properties. These data provide a means to investigate long-term climate change. It is also useful for studying local and/or periodic phenomena such as precipitation patterns, sea surface temperature anomalies.

Surface Temperature

Several sensors are useful to derive land surface temperature; in particular those with bands in the thermal infrared range are suitable (mainly 4100-4250nm and 13000-15400nm). The available sensors used for surface temperature have different characteristics in terms of spatial and temporal resolution. Spatial resolution varies from 60m (like Landsat ETM+) to 45km (MRIR on NIMBUS03) and the temporal resolution varies from 20 minutes (Meteosat) to several weeks.

Atmospheric Temperature

Atmospheric temperature is necessary for numerical weather predictions or tracking global change. Remote sensing satellites can provide data to derive atmospheric temperature.

In general high spatial resolution is not required for these types of measurements. Often use is made of instruments called sounders which sometimes even have a combination of infrared and microwave bands. Instruments typically made for this purpose are the HIRS series (part of TOVS) and 174-K. ISTOK-1 and MODIS are very valuable instruments for monitoring atmospheric temperature.

Rainfall

The NDVI derived from NOAA-AVHRR images is highly correlated with the Cold Cloud Duration (CCD) images from METEOSAT. The combination of these two images provides a good indicator of effective rainfall in areas receiving less than 1000 mm rainfall each year[6,7]. They are particularly useful where ground-based meteorological stations are few and/or poorly dispersed. The availability of such images would be very useful for seasonal studies of the environmental factors associated with vector-borne diseases, rainfall in particular. Since 1995, rainfall estimates for the African continent, calculated from both CCD and weather models, have been distributed every 10 days over the internet[8].

Humidity

Instruments on several remote sensing satellites can derive humidity profiles. Bands between 6700 and 8200 nm and around the 13300nm and 18600nm are used for this purpose. Sensors like MRIR, THIR/1,HIRS/1, HIRS/2, VISSR & VAS, MVIRI, VTIR, STR, HIRS/3, ISTOK-1, MSV & IR, MODIS, SEVIRI and IASI are used to gather humidity profiles.

3.2.3 Summary of the Remote Sensing Capabilities

The following table shows some of the available sensors that can be used to identify or map the environmental factors related to the distribution of malaria. The sensors are ranked by spatial resolution and then by spectral resolution. For each sensor, the possible factors are indicated. Appendix F shows an overview of relevant satellites that can be used to monitor or map the ecological parameters mentioned here above. A proposed micro-satellite alternative is also included in Appendix G.

Table 3.3 - Satellite Sensors for Mapping Environmental Factors Related to Malaria

	Satellites	Spatial Resolutions (Spectral bands)					Temporal (days)	Identified or mapped Environmental Factors				
		Panchromatic (m)	VNIR (m)	SWIR (m)	TIR (m)	SAR (band)		Land cover	Deforestation	Wetlands, Soil moisture	Water bodies	Climate factors
Very high Resolution (<5m)	Ikonos	1	4				11	X			X	
	[Orbview-3]	1	4				3	X			X	
	Quickbird-2	0.61	2.5				4	X			X	
	Spot-5	5					3	X			X	
	[Radarsat-2#]	3				3 C	6					
High resolution (5-30 m)	CBERS CCD	20	20				26	X	X		X	
	ENVISAT-1					30 C	3		X	X	X	
	ERS 2					30 C	35		X	X	X	
	IRS 1C &1D	6	23	70			24	X	X	X	X	
	Landsat 5		30	30	120		16	X	X	X	X	
	Landsat 7	15	30	30	60		16	X	X	X	X	
	LightSAR					25 L	10			X		
	Radarsat					10 C	6		X	X	X	
	[Radarsat-2#]					3 C	3		X	X	X	
	SPOT-2	10	20				26	X	X		X	
	SPOT-4	10	20	20			3	X	X		X	
	SPOT-5	5	10	20			3	X	X	X		
	Terra	30	30	30	30		16	X	X		X	
	[ALOS#]	2.5	10			10 L	45	X	X	X	X	
Medium Resolution (60-100m)	ADEOS-2		250	250	1000		4	X				
	Resurs-O1N2/3		170		600		4	X	X	X		
	Resurs-O2		170		600		4	X	X	X		
	IRS-1C		188					X		X		
	Terra		275					X	X		X	
	Radarsat1&[2#]					100 C			X	X	X	
Low resolution (0.5-5 km)	ENVISAT #		1 km	1 km	1 km			X	X	X		X
	ERS-2		1 km	1 km			35	X		X		X
	SPOT-4&5		1 km	1 km			1	X	X	X		X
	Veg.		1.1 km	1.1km	1.1 km		0.5	X	X	X		X
	NOAA-12		1 km	1 km	1 km		0.5	X	X	X		X
	NOAA-10&14		1.1 km	1.1km	1.1km		0.5	X	X	X		X
	NOAA L, M &N		1.13km	1 km			2		X			X
	Orbview-2		0.5 km		1 km		2		X	X		X
	Terra	2.5km			5 km		0.02				X	X
	Meteosat series		1&4km									X
	GEOS					4-38km	0.07					X
	TRMM											

[ ]: Satellites that are planned to be launched.

Panchromatic:	*Grayscale Visible images, wavelength region (400 - 700 nm)*
VNIR:	*Visible and Near InfraRed (400-1300 nm)*
SWIR:	*Short-Wave Infrared (1300-3000 nm)*
TIR:	*Thermal Infrared (3000+ nm)*
SAR:	*Synthetic Aperture RADAR (SAR bands: K: 1-2 cm, L: 15-30 cm, P: 30-100 cm, S: 7-15 cm, X: 2-4 cm, Q: 1 cm and W: 0.3 cm)*

3.3 Global Navigation Satellite Systems

The location of affected people is an important parameter for the monitoring of malaria and early detection of epidemics. Adding to the difficulty of identifying malaria cases (people not aware of their disease, wrong diagnosis), the necessity to precisely locate the cases within large areas is sometimes insurmountable due to absence of settlement names identified on maps and population migration. For example, in countries such as Sri Lanka or Kenya, the movement of people and the creation of new settlements make the collection of relevant data very difficult[9].

In these cases, the use of a Global Navigation Satellite System such as GPS not relying on maps or local infrastructure can be of great help.

The GPS system consists mainly of 24 satellites on 6 different orbits, 20,000km above the Earth. The satellites transmit radio signals that include information such as their position and current time. A GPS receiver can determine its location with great precision using this information and suitable algorithms. A very simple receiver can achieve a precision of 100m or less which is sufficient for approximate localisation in a rural area. Civil applications of the GPS system have grown dramatically in recent years. Hence, the cost of a GPS receiver is now very affordable. On the ground workers may then easily be equipped with such a valuable tool.

A possible problem can occur in regions with dense forests, where the canopy blocks the direct line-of-sight to the satellites. As malaria cases occur in villages, mostly situated in the open or at the borders of the forest this limitation should not be a real challenge in most cases. Otherwise, the user can move to an uncovered area and transmit an approximate localisation.

An example of the use of GPS to locate malaria cases can be found in the malaria control programme of the northern KwaZulu-Natal[10]. Approximately 35000 homesteads were captured using GPS during 1994 and 1995 allowing the malaria cases to be displayed at homestead level.

3.4 Communication Satellites for Transmitting Ground Data

Ground based measurements taken *in situ* are important for several reasons. The method to measure different parameters will not be discussed in detail here, but more generally. Accurate measurements of factors such as temperature, humidity, water level can be obtained on the ground. Ground based measurements provide more precise information at certain positions and could be used to help calibrate and verify satellite data. For such a system to have effects in an early warning system, the measurements must be transmitted in near real time. To do this, the system needs to have an integrated telecommunications system. Since many developing countries do not have a telecommunications infrastructure, a satellite telecommunication system would be the best solution. The telecommunication technology already exists and is used in buoys[11] for collecting meteorological data at sea.

This approach is not only relevant to help calibrate and verify satellite data but could be applied to monitor directly the population of mosquitoes.

As mentioned in Chapter 2, a close link exists between the number, the species and the gender of mosquitoes and risk of malaria. Acoustical Detection Method (ADM) using an acoustic sensor can be applied to distinguish male and female mosquitoes, different species of mosquito, an individual and/or a large group of mosquitoes' flight through the monitored zones[12]. Another way to achieve this result is to use a dedicated optical sensor (Appendix G). Although back in 1994, research focused on this topic had shown very prosperous results, it was considered too costly to transmit the data to remote centers so mainly all surveillance was manually done on sites. Opportunities to use a single slot of telecommunication satellite,

the existence of messaging satellites such as Orbcomm or even the availability of constellation of telecommunication satellites (*e.g.* Iridium, Globalstar) could render the feasibility of sensors monitored from space much more affordable. Furthermore, if a proper estimate of number of mosquitoes has to be done, a number of sensors need to be implemented over fairly large areas and it may not always be possible to collect the data manually on a regular basis.

Therefore, ground data collection (more precise numbers of mosquitoes and their type) using space relays appears to be a promising way to monitor very precisely malaria outbreaks and even monitor the impact of changes in environmental parameters or prevention policies on population of mosquitoes. Availability of such sensors can provide inputs for prevention policies as well as outputs to assess the efficiency of policies of mosquitoes' eradication.

The weakness of such a system is that it may only cover a small area or that many sensors are needed. The effective implementation of this idea is dependent upon the availability of cheap sensors to cover large areas threatened by malaria. One of the solutions to have low cost mobile sensors could be to use small helium balloons carrying sound sensors and a tracking system that could send a short warning message when a threshold of a specific mosquito sound signatures is reached in one area. Localization and data transmission of the measurement could be provided by an Argos or Orbcomm like satellite technology.

However, regarding the space segment, a cost effective strategy relying upon the use of microsatellite (see Appendix A) could be proposed and would make the overall approach very promising.

3.5 Conclusion

As explained in section 3.1, remote sensing satellites can map some of the most important ecological factors related to the distribution of malaria such as vegetation type, deforestation, soil moisture or surface water. Remote sensing satellites can also measure the meteorological parameters such as climatic factors for large areas. These factors are used in mathematical models that predict the weather *e.g.* rainfall, temperature and humidity which are of great importance to monitor and predict climatic changes expected to affect malaria distribution.

Nevertheless, the ecological parameters are not sufficient for an accurate monitoring and prediction of malaria outbreaks. They can be complemented by ground data coming from sensors or from medical surveys. In both cases, space technology can be very useful either to locate remote villages subject to malaria outbreaks and to get the resources to the correct place (GNSS) or to transmit the collected data to appropriate processing centers (telecommunication satellite).

Once the data are collected, they have to be analyzed and processed in order to assess and predict the risk of malaria in the areas considered. The next chapter presents how these risk maps can be made and which additional data can be relevant to improve their accuracy.

3.6 References

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MIS: Malaria Information System

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Chapter 4 - MIS: Malaria Information System

4.1 General Introduction

MIS is a Geographic Information System (GIS, see section 4.2) dedicated to malaria. It provides spatial information about the distribution of areas of high malaria risk. This system is based on remotely sensed and ground based data and existing health information databases. The system provides the ability to identify risk areas and assists decision makers in directing resources and strategies. Furthermore, it can be used as a malaria early warning system that forecasts potential malaria outbreaks.

As noted in Chapter 3, sensors mounted on satellite and aerial platforms gather multi-spectral data and SAR images. These remotely sensed images could be incorporated into GIS databases. RS and GIS are most useful if disease dynamics and distributions are clearly related to mapped environmental variables[1]. For example, if a disease is associated with certain vegetation types or environmental characteristics (as described in Chapter 2) RS and GIS can identify regions where risk is relatively high. Similar information systems based on GIS already exist (*e.g.* MARA - Mapping Malaria Risk in Africa; and LSDI Malaria Control Program which covers areas of Mozambique, South Africa and Swaziland) but are based on historical data. Space technology, especially remote sensing systems can improve the output quality of information from existing MIS.

4.2 What is GIS

4.2.1 General Description

GIS is a set of computer-based tools for analyzing spatial data. These tools consist of software programs and subroutine packages containing the elements necessary for working with spatial data. GIS provides computerized capture, storage, management, analysis, retrieval, and display of spatial and descriptive data that is geographically referenced to a common coordinate system. It contains a database (spatial and attribute), data input, a cartographic display system, database management and a geographic decision tool. The spatial database describes spatial features with digital coordinates[2].

GIS software provides the functions and tools needed to store, analyze, maintain and display geographic information. Key software components are:

- Tools for the input and manipulation of geographic information
- A Database Management System (DBMS)
- Tools that support geographic query, analysis, and visualization
- A Graphical User Interface (GUI) for easy tool access

Today, GIS software runs on a wide range of hardware types, from centralized computer servers to desktop computers used in stand-alone or networked configurations. The central piece of equipment is the workstation, which runs the GIS software and is the attachment point for ancillary equipment. Hard copy data requires the use of a digitizer for conversion of hard copy data to digital data. A GPS data receiver can be used to collect data in the field. The use of these handheld field devices is becoming an important data collection tool in GIS. With the introduction of web-enabled GIS, web servers also have become a useful component for sharing GIS analysis.

Datasets are possibly the most important components of a GIS. Geographic data and related tabular data can be collected in-house or purchased from commercial data providers. A GIS integrates spatial data with other data resources. Most organizations use a DBMS to organize, maintain and manage their data. Figure 4.1 shows an example of a composition of different data layers to be implemented and analyzed in the MIS.

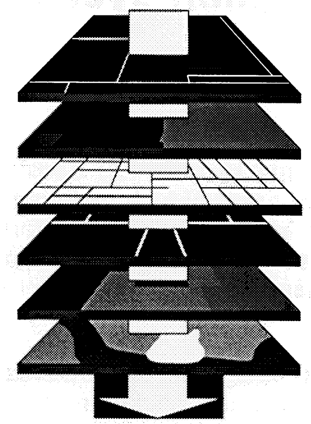

Figure 4.1 –GIS Data Structure

Without the **people** who manage the system GIS technology is of limited value. Skilled personnel can create useful information from the basic data and apply it to real-world problems. GIS users range from everyday end users to technical specialists who design and maintain the system.

4.2.2 Data for GIS

The user must know the desired accuracy, quality and scale of the MIS output. The accuracy of the MIS output is a direct result of the quality of the data input. For example AVHRR images with 1km spatial resolution cannot create maps with an accuracy of 100m.

Gathering data for GIS can be done in three different ways:

- Creating your own data
- Buying standard data
- Ordering a specific customized dataset.

To assess the usefulness of a particular geographic data set the user must know the spatial extent of the data, how the data was gathered, the resolution and accuracy of the data. The information required to assess the usefulness of a dataset is called metadata. Further information about data capture, data formats, data storage and metadata can be found in Appendix B.

4.3 Information Useful for MIS

As noted in Chapter 2, the incidence distribution of malaria is strongly affected by environmental and eco-epidemiological parameters. Numerous factors determine the particular malaria situation from one place to another. Since these factors are not all equally distributed, accurate, relevant and timely information is required before malaria control can be planned and resources allocated. The two major factors that affect the distribution of malaria are temperature and rainfall. Rainfall is the source for mosquito breeding sites and correlates with humidity and therefore with vector survival. Temperature maps can indicate low temperature and thus mosquito free areas.

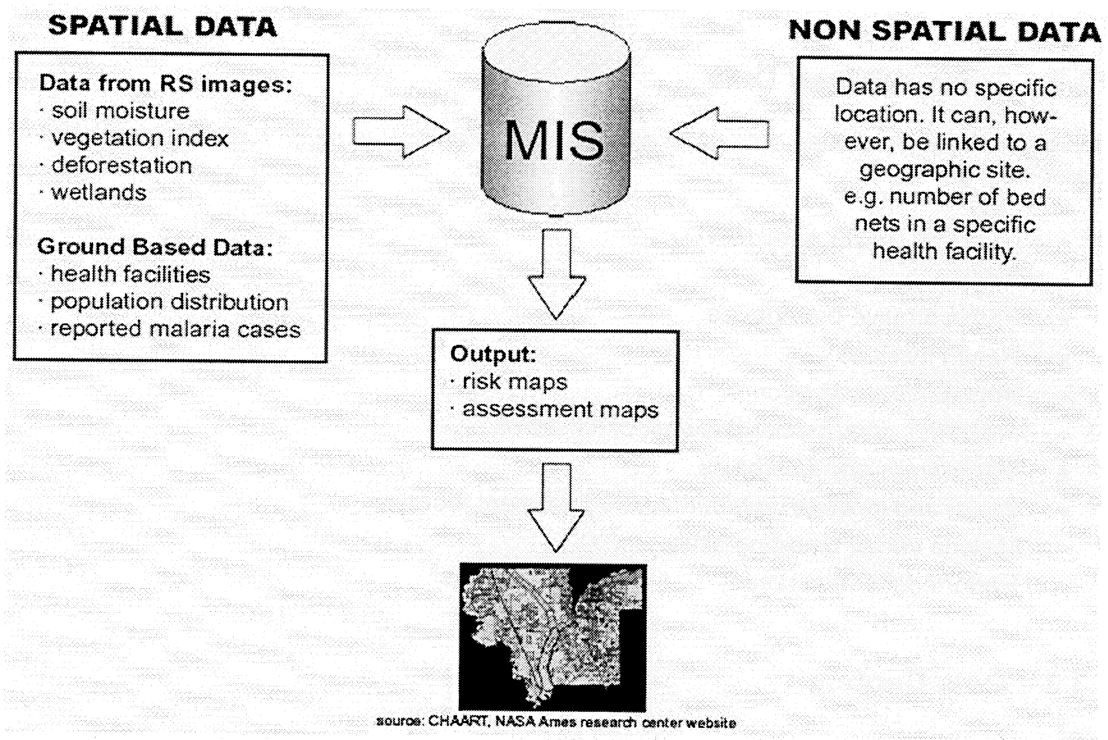

Figure 4.2 - Malaria Information System (MIS) Model

Figure 4.2 shows a basic model of the MIS. The input is spatial and non-spatial (attribute). The GIS expert needs both data-types to analyze the malaria risk and take the right measures to reduce possible impact. A spatial or geographic data set is a collection of data individually or collectively attached to geographic location. Non-spatial data or attribute data describe the characteristics of the spatial data entities. An example of non-spatial data is the number of bed nets currently available in a specific location.

Metadata standards (as described in Appendix B) are needed to enable dataset integration. Without standards it is unlikely that bringing datasets together or comparing them will yield accurate and valuable interpretations. For instance, if different organizations create data sets using different definitions for categorizing vegetation types, a comparison is useless or at least labor-intensive. Currently, two important metadata standards are set by the U.S. Federal Geographic Data Committee (FGDC) and the International Organization for Standardization (ISO) 19115/TC 211.

4.3.1 RS Data

Remotely sensed data is one of the most important inputs into MIS. Different mandatory data layers are discussed in Section 3.2.

4.3.2 Ground Based Data

A core set of ground-based data must exist at a national level to support decision makers. Examples include:

- Location of river networks
- Roads
- Administrative boundaries
- Health facilities
- Population distribution
- Industrial, commercial and residential areas
- Water wells and boreholes
- Water and sewage distribution and treatment facilities
- Malaria vector breeding sites
- Reported malaria cases.

4.3.3 Data Centers

Remote Sensing Data centers are governmental and non-governmental institutions. They provide global, continental or national data, which can be obtained via Internet or via mail on optical media such CD or DVD. Some major global centers are:

- US National Oceanic and Atmospheric Administration (NOAA)
- Earth Resources Observation Center (EROS)
- The Land Processes Distributed Active Archive Center (DAAC)
- United Nations Environmental Program (UNEP) Data Portal. (Appendix C)

Most of the remote sensing operators and providers offer several kinds of data in different data formats from which the user must select appropriate sets.

The following GIS data centers, distributing only Africa-related data, have been founded recently:

- Africa Data Dissemination Service (ADDS)
- EIS-AFRICA
- CARPE - Central Africa Regional Program for the Environment
- CPC Africa Data Archive

Most of these centers have partnerships with the major global centers mentioned above.

4.4 Integrating Existing Databases for MIS Forecast and Prevention

Malaria occurrence is influenced by numerous phenomena outside the framework of health systems (including population movements, environmental changes, and agricultural practices). Therefore the malaria information system should be able to incorporate and use these different types of information. Over the last two decades, considerable effort has been put into the development of geographical information systems and satellite data. These systems provide a framework in many sectors. For example, the United Nations Food and

Agriculture Organization (FAO) has used data from weather monitoring satellites for many years in order to monitor and assess environmental conditions related to food security[3]. Organizations concerned with bio-diversity such as World Wildlife Fund (WWF) make use of GIS data for vegetation type and cover[4]. This might also be useful to integrate in MIS. Many countries have already invested in the establishment of information systems (see Table 4.1) helpful in combating malaria.

Table 4.1 - Information systems valuable for MIS

Agricultural Information Systems. Provide information on agricultural production patterns and performance, agricultural trade, agricultural inputs, farming systems, and rural income levels.
Land, Water and Climatic Information Systems. Provide geo-referenced information on topography, landform, characteristics of soils, climate, agro-ecological zones, water availability and use, land use and land cover, arable land, land suitability and productivity, land tenure, irrigation, water rights and infrastructure. In some cases geo-referencing may be done with GPS systems. This is highly recommended to increase MIS standardization.
Food Security and Nutrition Information Systems. Provide information about food availability including access to food.

The above efforts in developing information systems should be supported. Duplication of databases within a country should be avoided or minimized. With this in mind the partnership among the health, meteorological, and agricultural communities is essential. Partners from different sectors must learn new ways to work together, share and update data resources and ideas in order to improve the cost-effectiveness of their individual programs. Thus, the development of a national MIS might require the establishment of cross-links between already existing databases.

4.5 MIS Output

4.5.1 MIS-based Analysis and Visualization of Malaria Risk Areas

MIS is a primary tool to support the decision making process for central government and for local authorities. Frequent malaria data analyses and visualizations are important for the planning, logistics, and operation of malaria control programs. The national Malaria Information System should be able to:

- Incorporate the data sources (see section 4.2) within MIS and other existing information systems (see Table 4.1).
- Deal with the spatial aspects of this information.
- Produce routine malaria risk evaluations.
- Classify areas based on a set of predefined rules.
- Automate generalization of the map information.
- Produce feedback to government officials, health personnel and general public.
- Allow external access and queries (*e.g.* over Internet) for authorized national or international (WHO, tourism organizations) bodies.

As already described in section 4.2.1 MIS has many layers showing different types of (sometimes very complex and diverse) information. It is very difficult to foresee all possibilities to present spatial data or what specific applications will be necessary. However,

the main objective of data analysis is to identify patterns and relationships between malaria cases and environmental conditions.

In addition, the analyses and visualization of various MIS data might be dedicated to:

- Monitor changes in the distribution and incidence of malaria over space and time. Evaluate the effects of new infrastructure objects on the distribution of malaria.
- Identify the current distribution and density of the population in malaria risk areas.
- Provide maps essential to inform tourists, investors and decision-makers in the malaria risk areas, and changes that occur over time.
- Assist planning of water resource developments.
- Establish a model describing relationships between disease data and current climate variables.
- Analyze the models based on future predictions for climate.

The results of malaria risk analyses are visualized in different ways, most commonly as maps completed with written reports. In the following sections the main types of MIS outcomes (see Figure 4.3) will be discussed in more detail.

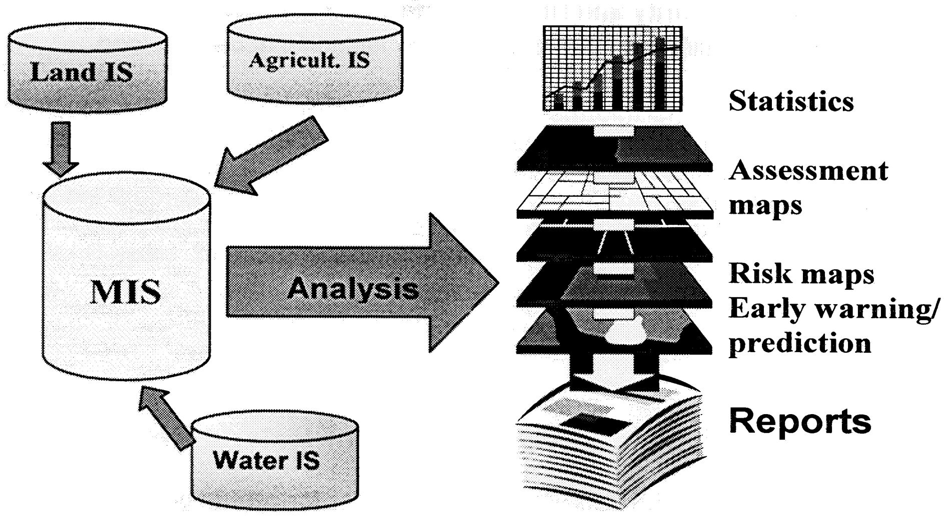

Figure 4.3 - MIS Output

4.5.2 Malaria Assessment and Risk Maps

Malaria assessment maps are used to investigate the cause and spread of malaria. These maps can correlate outbreaks of malaria with specific environmental conditions (and their changes over time). Maps should provide easily understood visual information about the location of epidemic areas and vulnerable population groups. Once these locations have been detected, a wide variety of other data relevant to understanding and monitoring of malaria can be over-laid on the existing digital maps. When compiling malaria assessment maps the thematic base maps on altitude, relief, soil type, water table, geomorphology and water quality are complementary. According to India's experience[5] such maps at a scale 1:50000 might be considered.

In Chapter 3 it is shown that MIS can significantly contribute to malaria studies with regularly updated satellite data. Map scales depend on the rank of authority (central, regional or local) to which the malaria assessment maps are addressed, and can have a large variety.

Increased resolution of maps allows more precise execution of malaria combat activities, resulting in greater cost effectiveness of these efforts. Required resolution depends on many factors, such as density of population, environmental conditions and season (high or low risk period).

This large variety of required map scales and resolutions sets additional requirements for the MIS capability to automate the generalization of malaria risk maps to address all needs of end-users.

Main users of the malaria assessment maps are:

- Governmental administrations
- Research institutions
- Health institutions and organizations

Governments and research organizations can use assessment maps to monitor population disease level, to maintain current inventories of medicines and other supplies, and to track the availability and location of health personnel needed in emergencies.

Malaria risk maps can be compiled based upon the malaria assessment maps. Malaria risk maps show the malaria risk areas and are essential for officials and individuals. Depending on the required resolution of the specific remote sensing data, the time span between two consequent updates of maps varies. Apart from the end-users listed malaria risk maps are also very useful for tourism activities. They can provide useful information for travel agencies and tourists to determine the appropriate preventative precautions when visiting malaria risk areas (*e.g.* vaccinations may be required).

Low-resolution risk maps are already available on internet. Some of these international initiatives are briefly described in Table 4.2, more explicit information about these programs can be found in Chapter 6.

Table 4.2 - Available Malaria Risk Maps

The US Centers for Disease Control and Prevention[6] publish information about malaria risk all over the globe. This information is very general and coarse and mainly traveler oriented. The malaria risk maps produced by MARA[7] (available for most African countries) are based on a theoretical model using available long-term climate data. It has a resolution of about 5x5 km. Nevertheless, occasionally maps are not based on actual malaria data and may not reflect the real malaria status. More detailed risk maps are compiled within the Lubombo Spatial Development Initiative (LSDI).[8] These maps are based on retrospective case data and indicate the information on district level in southern Africa. A collaborative initiative is currently underway to establish a Geographic Information System, which will allow cases to be plotted at village level and thus allow more accurate maps. The LSDI initiative deserves attention in order to share the experience about the possible implementation problems and details.

Regular and up-to-date remote sensing data leads to more accurate and reliable malaria risk maps. Therefore the HI-STAR team proposes the use of space technology products as described in Chapter 3 to complement the malaria risk maps primarily based on historical datasets.

It is foreseen that seasonal meteorological forecasting will become more reliable and thus become more useful in forecasting malaria risk. The improved accuracy of weather forecasts and global climate change models can efficiently be employed for early malaria risk detection.

4.5.3 Malaria Early Warning System

The early detection, containment and prevention of malaria epidemics are essential components for optimizing malaria combat resources. Decision-makers need to be aware of:

- Location of areas most likely to suffer a malaria outbreak
- Time in which malaria epidemics are most likely to occur

In order to fulfill the above requirements, a Malaria Early Warning System (MEWS) can be implemented as a module of MIS. This acronym - MEWS - has been introduced in the Roll Back Malaria document 'Malaria Early Warning System'[1].

As proposed by Thomson and Connor[3], MEWS also includes some of the space applications. However, the infrastructure for MEWS is not yet implemented in practice. To ensure timely and appropriate compilation of malaria epidemics forecast, contemporary satellite technology should be applied more extensively. Thus, the contribution of the HI-STAR team to MEWS is to suggest research and use of up-to-date space technologies, as described in Chapter 3.

4.5.3.1 Main Factors in the Malaria Early Warning System

Three types of indicators are used within MEWS to predict malaria epidemics:

- Long range weather forecasts and indicators
  - Sea surface temperature
  - El Niño
  - Global climate changes
- Meteorological weather forecasting
  - Rainfall prediction
- Number of detected malaria cases

The first types of indicators are climate-related variations like sea surface temperature and sea level. These large-scale environmental changes are likely to lead to higher incidence of vector-borne diseases (malaria in particular) even in southern regions of the United States and in Mediterranean countries.

Recent studies have demonstrated links between El Niño Southern Oscillation (ENSO), and inter-annual climate variability and the risk of malaria in Asia, South America and Africa[9,10,11]. In years following El Niño (especially the first year) a high risk of malaria and excessive rainfall can be expected. Higher temperatures during El Niño episodes may also favor malaria transmission[8,12]. Continuous monitoring of El Niño and its effects on malaria can give a possible new indicator that can be used in MEWS.

Malaria Early Warning Systems also make use of meteorological indicators, as abnormal meteorological conditions are the most common causative factors in malaria epidemics. Temporary meteorological changes can perturb the ecological equilibrium between hosts, vectors and parasites. Rainfall is the most commonly used indicator for MEWS. A last group of indicators are those related to malaria monitoring. Typical indicators are malaria case threshold levels at medical facilities.

The importance of a Malaria Early Warning System is illustrated by Figure 4.4. Based on the 1997/98-experience of the malaria control staff in Tanzania, Uganda and Kenya, a three-tiered approach for malaria epidemic forecasting can be proposed[13]. Each tier is associated with specific indicators and responses. In the simplified example presented in Figure 4.4 a

first warning flag (Flag 1) is raised at the regional level after sea-surface temperatures suggest an impending El Niño event. Subsequent rainfall is monitored directly as part of an early warning system and in the event of excessive rainfall Flag 2 is raised. Malaria cases are then monitored at the individual facility level (Flag 3) and if a defined threshold is exceeded an epidemic is declared.

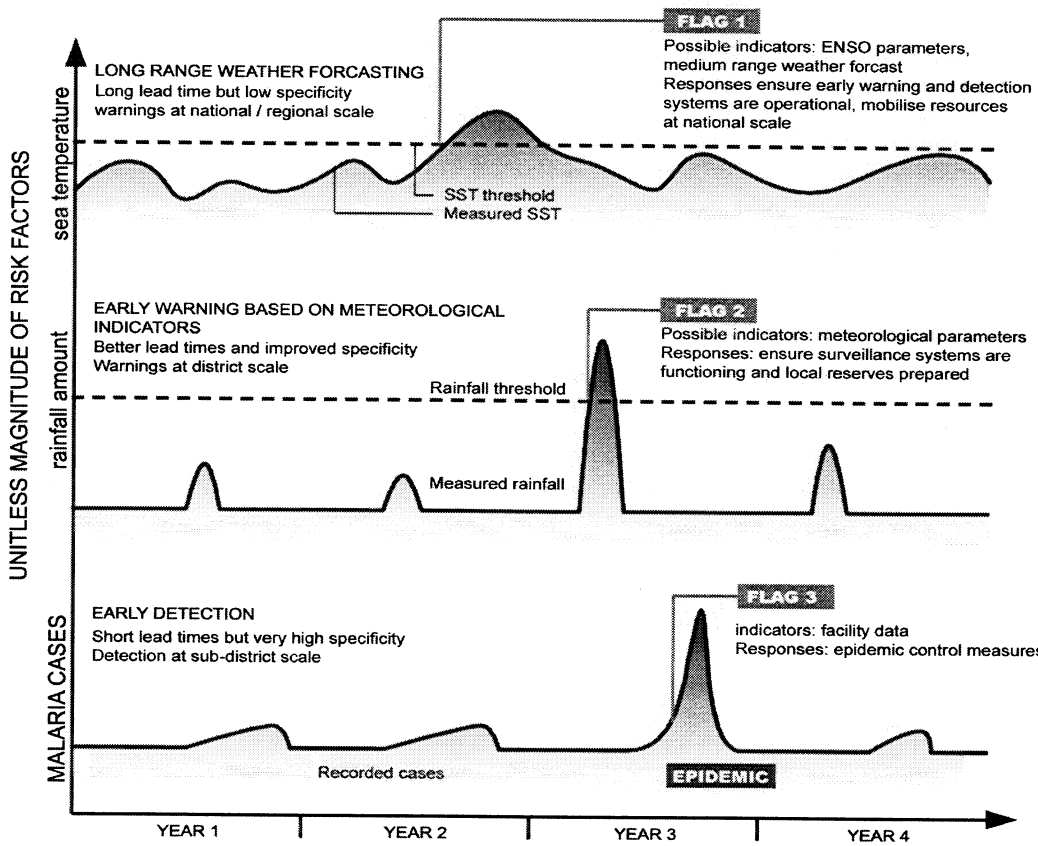

Figure 4.4 - Forecasting malaria epidemic in East Africa.
Correlation between ENSO related risk factors and malaria cases.
Adapted from (Anon 1999).

From Figure 4.4 one may deduce that monitoring of the sea surface temperature is a key issue for enhancing malaria risk detection. Fortunately, the sea surface temperature can be continuously monitored by satellite technology (see also Chapter 3). Recent advances of space applications provide the ability to forecast the climate 3 to 6 months ahead. Consequently this improves epidemic preparedness in vulnerable regions.

4.5.3.2 Applicable models for a Malaria Early Warning System (MEWS)

In a MEWS, any existing models of malaria dissemination are most likely to be completed with statistical analyses at a national (and/or regional) MIS center. Statistical approaches rely on empirical statistical relationships between historical sets of observations such as rainfall and sea surface temperature (SST) patterns. These are helpful for further scientific understanding of the underlying mechanisms.

Seasonal climate forecasting (up to six months in advance) using global circulation models has developed rapidly during the last decade. Recent developments in dynamical modeling have led to atmospheric-ocean coupled models, which allow real-time prediction of the sea

surface temperatures around the globe. These models successfully predicted the onset and demise of the 1997/1998 ENSO event and its impact on weather in Africa. The excess rainfall correctly predicted from these models[14] in East Africa in 1997/1998 was associated with devastating malaria epidemics.

The main MEWS tools, however, are seasonal weather forecasts. These are used to predict major climate trends over a period of several months. They indicate areas where there is an increased likelihood of some deviation from the climatic mean, such as wet or dry, warm or cold conditions. A seasonal forecast is usually limited to the probability of temperature or rainfall being above, near, or below normal, without quantifying the deviation. Predictions are better for some seasons than for others. At the moment seasonal forecasts are only available for certain regions and for certain months, however there is clearly the potential to extend such forecasts to other regions[15]. Here, the monitoring of environmental conditions by using weather satellites (as already shown in Chapter 3) is the best tool to improve the existing forecasts. The increasing capabilities of a Malaria Early Warning System should be integrated within the MIS.

4.5.3.3 MEWS Functions

The principles of malaria early warning system activities are also described by Thomson and S.J. Connor[16]. The following section is partly adapted from their work. The MEWS includes not only prediction, but also the severity of the malaria impact. Three main groups of indicators to predict the timing and severity of a malaria epidemic are used. Only the first group is new and is directly related to the severity of the impact.

- Vulnerability indicators (such as low immunity, malnutrition, HIV, population movement, drug resistance *etc.*) which may be monitored continuously and are likely to predict the severity of impact, rather than the timing of, an increase in malaria transmission
- Early detection indicators from health facility malaria morbidity data (using epidemic thresholds) that may be used to confirm the onset of an epidemic situation and predict the magnitude of the epidemic 3-4 weeks in advance.
- Transmission risk indicators (such as unusual increases in rainfall) that may predict the timing of an increase in malaria transmission 2-4 months before a malaria epidemic occurs. In some situations a higher than average seasonal rainfall may be predicted from seasonal climate forecasts 1-6 months in advance—giving a maximum warning of an epidemic situation developing with 10 months early warning.

Figure 4.5 shows the annual planning cycle of malaria control activities. Those areas in the cycle which can take advantage of satellite technology are indicated.

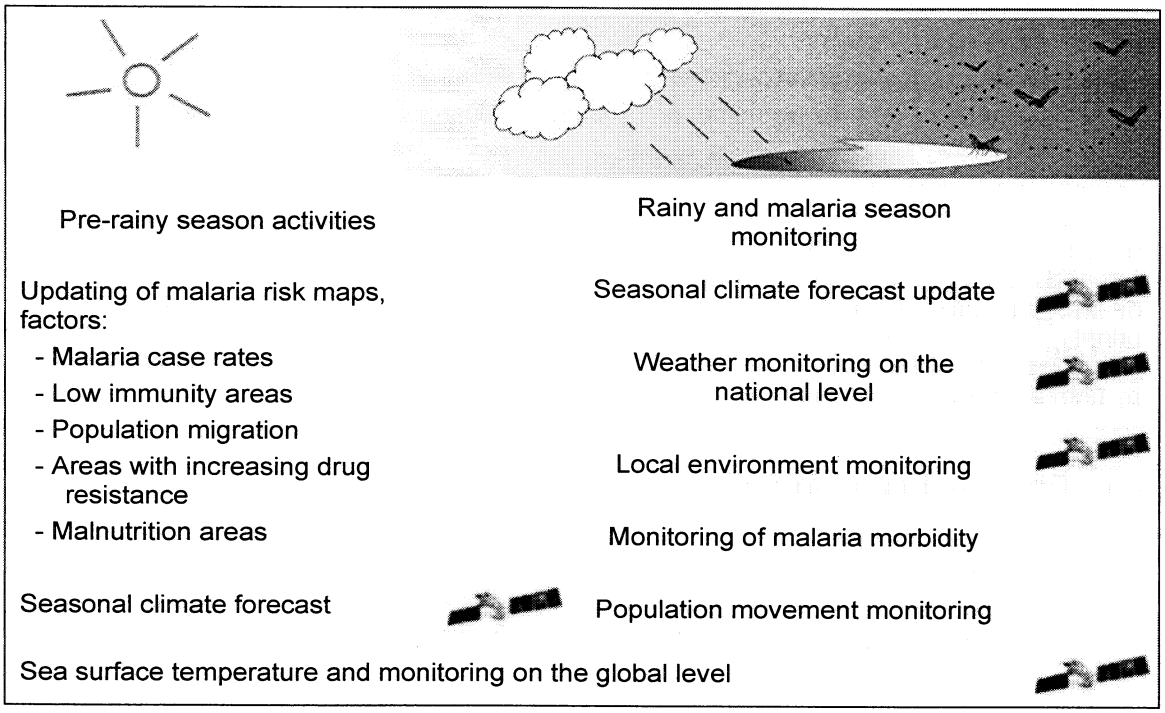

Figure 4.5 – Malaria Prevention Activities and Use of Satellites

The figure illustrates that space technology can become useful in Malaria Early Warning Systems. Especially weather monitoring, weather forecasting and long-term climate change predictions are possible candidates to be implemented.

4.5.4 Some Considerations for a MEWS Design

As it is demonstrated in previous sections, the climate forecasts at seasonal and inter-annual lead times may be of great importance in mitigating future epidemics in regions where a relationship between disease and global climate events (such as ENSO) exists. Seasonal forecasts can give a timely seasonal indicator of malaria risk. Improved estimation of El Niño effects on climate, rainfall and the length of the rainy seasons are of primary importance.

To summarize, in order to predict malaria epidemics with reasonable accuracy in a country, one should consider not only local weather monitoring, but also the global climate changes. The improvement of global climate models is an ongoing process. The accuracy of the models and prediction methods has been increased with the advance of the satellite technologies. The close cooperation of MIS with international research organizations in addition to analysis of national datasets is also required. Undoubtedly, this results in more precise national malaria forecasts. MIS is not only dedicated to the production of malaria risk maps but also dedicated to the improvement of malaria outbreak models as well. It may also be necessary to ensure free access to databases needed for malaria research in developing countries, in particular with regard to databases held in international agencies and in national institutions in developed countries.

The lack of professionals capable of dealing with the complexity of MEWS tasks is one problem area. To ensure successful functioning of MIS this training vacuum must be addressed. This shortfall suggests that dissemination of international experience (*e.g.* via a global MIS coordination center) might be very valuable.

Based on the capabilities of presently available and already planned satellite technologies our objective is that each national MIS should be able to provide:

- Monthly early forecast bulletins (rather than seasonal)
- 2 month epidemics lead time, or 1 month if accuracy significantly greater.
- Forecasts supplied as digital maps.

A lead time of two months permits the health sector to make necessary plans. With higher resolution resources can be used more effectively. With this in mind, attention should be focused on the use of satellite data for the short-term forecasts of epidemics[17]. Improvements of MIS can often be most effectively introduced in sequence, depending upon national priorities and current/expected resources, and building on lessons learned as the process continues. To fulfill the above goals, drafting of a national 3 to 5 year plan that is supported by both a strong national and international commitment is required.

4.6 Presentation of MIS Products

The presentation of MIS products is critically important. Evidently, shorter theme-specific reports that address the specific interests of a particular type of user are more desirable. Data analyses and visualization should be fully transparent and easily understandable. Results should be attractively presented in ways that facilitate the drawing of conclusions. Maximum use should be made of well-prepared and attractive graphs and maps that communicate patterns and complex relationships in ways that can be quickly understood. Depending on technological capacity within the country, media other than printed documents, such as radio, posters, town meetings, and computer networks, may be used to communicate information and reports generated by national MIS. Workshops to present and discuss results with subsets of users can be an extremely effective means to help decision-makers interpret and internalize results and their implications for policy. Here the capabilities of space technology by means of telecommunication can be used in more detailed approaches for MIS product dissemination are presented in Chapter 5. Investment in appropriate hardware and software, and training of national technicians in their use, will be essential components of modern and effective MIS.

4.7 MIS Data Policies

In the preceding sections it is shown that space technology can significantly contribute to the effectiveness of a MIS system, especially remote sensing data. To use these space-borne data it is valuable to look into current data policy issues. These issues are discussed in the next two sections.

4.7.1 MIS Data Dissemination

As MIS aims to enhance human health of developing countries suffering from malaria, its goals are consistent with International Law and UN Resolutions on its remote sensing activities. In 1974, Principles Relating to Remote Sensing of the Earth from Outer Space were taken into consideration by the Legal Sub-Committee of the Committee On the Peaceful Uses of Outer Space (COPUOS) of the United Nations. Its purpose was to formulate principles to contribute to international co-operation on data dissemination of remote sensing. According to Principle II, the MIS activities should be carried out for all countries, which combat malaria irrespective of their level economic level, social and scientific and technological development.

In regard to data, there are three categories; primary data, processed data and analyzed information. The MIS would deliver the appropriate data in accordance with the needs of developing countries who suffer from malaria. The primary data and the processed data

concerning the territory under its jurisdiction need to be available to the sensed State, especially taking into account the needs and interests of the developing countries (Principle XII).

When the MIS becomes operational, States participating in MIS shall inform the UN Secretary-General and make available any relevant information to other any developing countries that are affected by the MIS program (Principle IX).

4.7.2 MIS Data Copyright

Copyright Law[18] would protect the MIS Data from illegal dissemination and from unauthorized copying or piracy. It gives 'economic rights' that allow the creator for mass distribution, communication and financial investment for their dissemination, and 'moral rights' that involve the right to claim authorship of a work, and the right to oppose changes to it that could harm the creator's reputation.

The basic conditions for application of copyright are that the MIS data needs to be original (which reflects creator's idea) and to be made by human (not by computer). In the case of Remote Sensing data, the processing uses human-made software and so copyright law is applicable to the MIS data. In addition, there is no need to register the MIS data to protect its copyright since it should be protected as an original work upon creation.

The MIS database is to be protected by copyright law according to Article 5 of WIPO Intellectual Treaty that leads to Article 2 of the Bern Convention[19].

4.8 Cost Estimation of the System

In this section a first estimate of the costs of the MIS is described. The cost analysis is based on analogy costing and a bottom-up engineering approach. In this way the MIS does not differ from any other project. In this study we aim to use existing space infrastructure and therefore the cost estimation will be primarily focused on:

- Production (and/or procurement)
- Operations

The costing of the space segment is 'replaced' by data acquisition cost and thus part of the operations cost. To have a successful and sustainable system the focus in the design has to be on reducing the operation costs, particularly the cost of data, as this is the main cost driver in GIS systems in general. The costs of the system built-up and the operation costs are discussed in detail in the next sections.

4.8.1 System Creation Costs

As the MIS is not yet completely defined this section will give a methodology to calculate the total cost of the system based on the cost of the main subsystems. The total cost is easily calculated if the number and price of the subsystems are known. The main reason for this general approach is to make the costing method distinct and easily adaptable to different regions and countries. As costs of the subsystems get clearer, a better estimate can be deduced by the same approach without re-doing the complete costing exercise.

The first step in the approach is the identification of the main subsystems. In the build-up of the system the following cost subsystems can be identified:

- Setting up a small global co-ordination center preferably within an existing organization.
- MIS-system development
- Installing/leasing processing facilities in existing regional centers
- Installing new ground stations (regional centers)
- Installing communication hardware (to assure timely dissemination)

The total cost of the build-up of the system, the initial investment, I_{Cost}, will then be:

$$I_{Cost} = C_{Development} + C_{CoordinationCenter} + n_1 \cdot C_{RegionalCenter} + n_2 \cdot C_{ExistingRegionalCenter} + n_3 \cdot C_{DisseminationPoint}$$

where

I_{Cost}	=	Cost of initial investment
$C_{Development}$	=	MIS development cost
$C_{CoordinationCenter}$	=	Initial investment cost to start an office
n_1	=	Number of new regional centers (ground stations) needed
$C_{RegionalCenter}$	=	Initial investment cost of regional center
n_2	=	Number of existing regional centers used in the MIS network
$C_{ExistingRegionalCenter}$	=	Initial investment cost to implement MIS in an existing regional center
n_3	=	Number of dissemination points
$C_{DisseminationPoint}$	=	Initial investment cost of a dissemination point (including the start-up cost for training local people)

The costs of the different elements are based on costs of similar systems found in literature and/or partly based on personal communications with specialists in GIS and ground stations.

4.8.1.1 Development Cost

A first Rough Order of Magnitude (ROM) estimation for the development cost of the MIS is US $300,000. The development costs are mainly software engineering and testing of the equipment.

4.8.1.2 Cost of Starting up a Global Coordination Center

As only the initial investment costs are part of the production costs, the cost of starting up a global co-ordination center only consists of office supplies. Based on a similar study[20] these costs are estimated on US $35,000. Costs of buying an office are not taken into account as it is assumed the office is rented. The yearly rental costs are part of the operational costs.

4.8.1.3 Start-up Costs of Regional Centers

The costs of regional centers are split into costs for complete new regional centers with a ground station and costs to implement the MIS in existing regional centers. To lower the cost it is recommended to use as many existing centers as possible and to co-operate with organizations that have hardware available.

The cost of a complete 'grass root' regional center is approximately US $620,000[21]. As this is based on the cost of a sophisticated Real-time Acquisition and Processing Integrated Data System (RAPIDS, see Figure 4.6) it is assumed that this includes also initial training of local personnel at the regional centers.

The major parts of the cost of implementation of the MIS in an existing regional center are additional hardware, software implementation, initial cost of datasets (with a low refreshing frequency), and again the training of local personnel. A rough first estimate is US $80,000. Naturally these numbers will differ from country to country but as a first estimation they can be used.

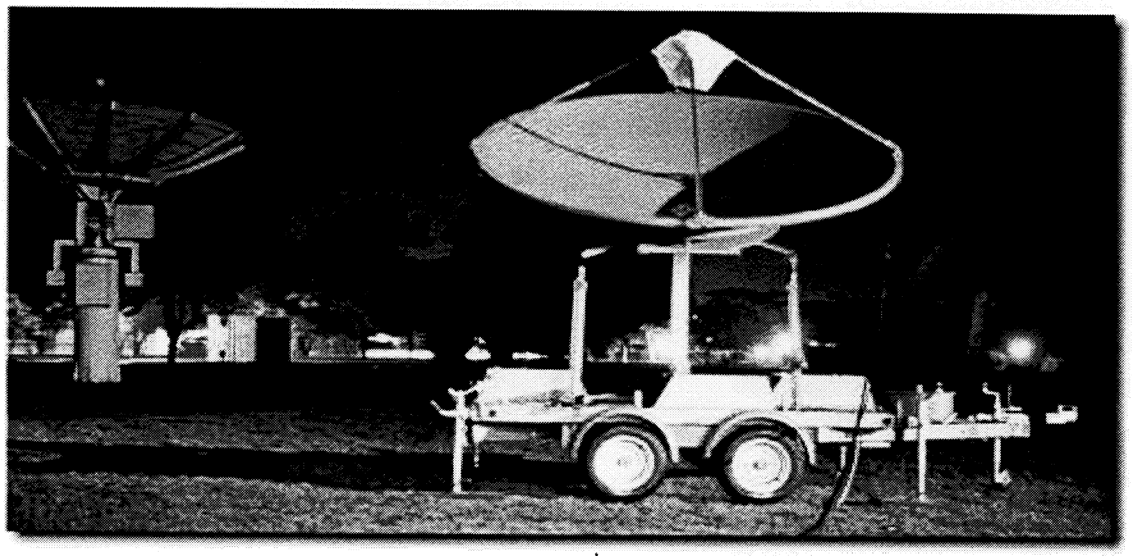

Figure 4.6 - Real-time Acquisition and Processing Integrated Data System

(courtesy of the National Aerospace Laboratory, The Netherlands)

When the total number of new regional centers and existing centers is known the start-up cost of the regional centers is given by the sum of the second and third terms in the given formula.

It has to be emphasized that the recurring costs are datasets, personnel and maintenance and these are part of the operation costs discussed later.

4.8.1.4 Start-up Costs of Dissemination Centers

The last major investment for MIS start-up is the cost related to dissemination centers. These are centers to where the information is distributed. To reduce the cost it is again recommended to use existing regional available resources. If such systems are not available new (expensive) hardware might be needed to disseminate the information. As dissemination centers are more numerous than regional centers it is of major importance for the success of the project to minimize these costs.

Typical costs of such dissemination centers are the hardware communication costs. A possible option is a Thuraya satellite mobile phone connected with a local PC. The rough estimation of such a system is US $4,500. Initial training of local personnel will add at least another US $1000. Therefore a complete new dissemination center will cost roughly US $5,500. A more simple approach would be just a satellite telephone without a local PC and transmitting the data verbally. This would cost US $700 and again another US $1000 for training.

The cost of a complete dissemination system can be calculated with the last term in the above formula when the number of new dissemination centers is known. Lowering the cost of a dissemination center is important to make the MIS also feasible where existing communication hardware is not available. Possible alternatives and new developments in communication in remote areas are described in section 5.1.

4.8.1.5 Total Creation Cost

The total cost to build up the complete system can be estimated by:

$$I_{Cost} = C_{Development} + C_{CoordinationCenter} + n_1 \cdot C_{RegionalCenter} + n_2 \cdot C_{ExistingRegionalCenter} + n_3 \cdot C_{DisseminationPoint}$$

4.8.1.6 Sample Case

A fictitious country with a population of 80 million people is taken as an example. This country has two existing regional centers with a satellite ground station. Four new ones have to be set-up. Approximately 700 new dissemination points are needed assuming that 1 dissemination point for 100,000 people is sufficient to cover the entire population.

Sample Cost Case	=	Cost (US$)
$C_{Development}$	=	300,000
$C_{CoordinationCenter}$	=	35,000
n_1	=	2
$C_{RegionalCenter}$	=	620,000
n_2	=	4
$C_{ExistingRegionalCenter}$	=	80,000
n_3	=	700
$C_{DisseminationPoint}$	=	1,700

Based on the numbers in the table above, a Rough Order of Magnitude (ROM) estimation of the investment cost to set up the MIS is US $4.2 million. It must be stressed that this does figure not include operational costs which are discussed in the next section and are partly based upon the depreciation of this investment cost.

The same cost estimation approach is used in the case studies in Chapter 7. More detailed information on the case study costing can be found in Chapter 7 and Appendix E.

4.8.2 Operation Costs

More important than the build-up costs are the operation costs as these costs are recurring. It is of major importance that the operations costs of the MIS are as low as possible. In fact the MIS is competing with other measures and systems combating malaria, therefore the costs have to be balanced by the benefits (see section 6.3) to make the system also successful in the long term.

The operation costs can be divided in costs related to:

- Cost of data (dependent on the number of datasets and updates)
- Cost of the downlink
- Regional center (ground station) maintenance
- Recurring dissemination cost
- Recurring education and training cost
- Cost of global co-ordination center

The costs are all calculated on an annual basis. As in the previous section the total cost is again the sum of the separate contributions:

$$R_{\text{annual}} = R_{\text{Depreciation}} + R_{\text{Datacost}} + R_{\text{Datalink}} + m_1 \cdot R_{\text{MISCenter}} + m_2 \cdot R_{\text{SharedRegionalCenter}} + m_3 \cdot R_{\text{DisseminationPoint}} + S_{\text{Coordination}}$$

where

$R_{Depreciation}$	=	Depreciation costs of initial investment (linear 10 year) = $I_{Cost}/10$
$R_{DataCost}$	=	Cost of updating data
$R_{Datalink}$	=	Data link cost
m_1	=	Number of MIS centers (not shared)
$R_{RegionalCenter}$	=	Recurring cost of a MIS regional center (not shared)
m_2	=	Number shared existing regional centers used in the MIS network
$R_{ExistingRegionalCenter}$	=	Recurring cost an existing (shared) regional center
m_3	=	Number of dissemination points
$R_{DisseminationPoint}$	=	Recurring cost of a dissemination point (including recurring cost for training local people)
$S_{Coordination}$	=	Share of the cost of a global co-ordination center. The costs are shared by 10 countries. ($S_{Coordination}$ = 10% of total global co-ordination center cost)

4.8.2.1 Cost of Depreciation

As a first estimate the depreciation of the initial investment will be assumed to be linear for 10 years. In the next phases of the program a more detailed depreciation scheme can be implemented.

4.8.2.2 Cost of Data

One of the major cost drivers for a GIS system in general is the cost of data. The cost depends strongly on the number of datasets needed, the update frequency, the type of data (how is it gathered) and the resolution. Low-resolution data can be obtained from providers at low cost or free. High-resolution data is expensive (*e.g.* 30 meter spatial resolution for 185 square km). Covering for example Nigeria with this resolution would cost US $30,000. High-resolution data would then become one of the main MIS cost drivers.

However, as a first estimate it is assumed that the satellite data will be provided free of charge. To further reduce the cost only necessary datasets shall be frequently updated. The cost of satellite data will then be limited to reproduction and dissemination to the regional centers.

Other GIS data needed for malaria maps has to be updated as well. The cost of this data collection and dissemination to the co-ordination centers and the regional centers is difficult to estimate. For a very first ROM it is assumed that at least two local employees are continuously busy with this task (US $22,000) at each regional center. Communication cost and travel cost will add another US $20,000 to a total of US $42,000.

4.8.2.3 Downlink Cost

If high resolution data is used, the downlink to the regional center (ground stations) can become a major contribution to the annual cost. To reduce the cost either low-resolution data can be used, or major discounts will be negotiated. In general the downlink cost must not be overlooked and therefore the costs are mentioned here separately. However as a first

assumption no downlink costs are implemented. They are assumed to be provided under humanitarian framework agreements (*e.g.* with ESRIN, EUMETSAT, *etc.*).

4.8.2.4 Regional Center Operation Cost

The operation costs of a regional center are mainly cost of personnel (one engineer and one technician). For a new regional center the costs are approximately US $22,000. When an existing regional center can be shared the cost can be reduced to US $10,000 per center. When part time employment of personnel or sharing of personnel is a feasible option costs can be reduced to US $5,000 per year per center.

4.8.2.5 Dissemination Cost

The dissemination costs are all recurrent costs related to dissemination of the information from the regional center to dissemination points. This includes cost of making reports and bulletins and can include satellite telephone costs, radio or television broadcasting costs. A ROM cost estimate for these costs is US $500 per dissemination point per year. Based on 30 minutes satellite-phone communication per month US $1/min and 12 reports (office supplies) per year.

4.8.2.6 Global Coordination Center

The cost of the global co-ordination office consists mainly of personnel cost, office renting, travel cost and communication cost. Based on a similar project[21] the total annual cost of co-ordination center with 9 people employed is estimated at US $1,100,000. The costs of the global center are shared by a number of countries. It is therefore assumed that only 10% is charged to one country.

4.8.2.7 Total Annual Cost

The total cost is now found by substitution in the following formula.

$$R_{annual} = R_{\text{Depreciation}} + R_{\text{Datacost}} + R_{\text{Datalink}} + m_1 \cdot R_{\text{MISICenter}} + m_2 \cdot R_{\text{SharedRegionalCenter}} + m_3 \cdot R_{\text{DisseminationPoint}} + S_{\text{Coordination}}$$

4.8.2.8 Sample Case

For the sample case the cost factors are shown in the table below.

Sample Cost Case	=	Cost (US$)
$R_{Depreciation}$	=	420,000
$R_{DataCost}$	=	42,000 (per regional center)
$R_{Datalink}$	=	0
m_1	=	4
$R_{MISRegionalCenter}$	=	22,000
m_2	=	2
$R_{SharedRegionalCenter}$	=	10,000
m_3	=	700
$R_{DisseminationPoint}$	=	500
$S_{Coordination}$	=	110,000 (10% of global center)

Dissemination is done by satellite telephone, and two employees per regional center look after the updating of datasets. It is assumed that the satellite data are provided without costs. A ROM cost estimation for the total annual cost for the MIS-system in the fictitious sample country is US $1.2 million. However US $110,000 is related to the global co-ordination center. In case of a pilot project these costs can be omitted. This leaves approximately US $1.1 million per year for operating the system. The operation costs of the Chapter 7 case studies are also estimated with the same approach. More detailed information can be found in Chapter 7 and Appendix E.

4.9 MIS Costs Benefits

The estimated costs in the former sections must be weighed against the economic benefits of MIS to estimate the financial feasibility. This section gives an overview of the benefits of the introduction of an MIS system in malaria programs.

Existing knowledge on the cost effectiveness of current anti-malaria programs is limited due to the fact that only a few studies exist on the subject they are difficult to compare against each other[22]. Nevertheless, it appears as if there would be a number of benefits associated with the establishment of MIS.

Firstly MIS will ensure a more efficient distribution of limited resources required for malaria prevention. This is the case because preventative measures and insecticides can be targeted more accurately using MIS. To illustrate the potential for MIS to distribute resources more efficiently, consider the example killing mosquitoes by indoor residual spraying[23]. This procedure costs US $16-$58 per disability adjusted life year (DALY)[24]. The risk monitoring capability of MIS will reduce this cost due to the fact that the procedure will be conducted in a more efficient manner. In other words, the maps provided by MIS will ensure that resources dedicated to spraying will be concentrated only in places where a malaria risk is likely to occur, resulting in less waste and lower cost per DALY. The same arguments hold true for the efficiency of treatment delivery. Placing emphasis on concentrating resources in problem areas will maximize the use of limited resources such as health care personnel and drug distribution.

Second, emphasis on prevention through risk monitoring is an important goal if the reduction of malaria infection is an end objective. In other words, while treatment is absolutely necessary, it will not reduce the global threat of being infected by malaria. Therefore, the prevention of malaria should be a long-term goal. While MIS can aid in providing treatment to those infected, the primary objective of MIS is on risk monitoring and prevention in order to reduce malaria infections. Successful implementation of MIS will result in direct macroeconomic benefits in that a more healthy population will be able to generate more wealth. For example in Mozambique malaria affects 90% of the population in some way and is the major cause of absenteeism from work and school, which has a negative effect on the country's productivity. This is the case in many African countries. One study has estimated that due to malaria, Africa's economic growth has been retarded by up to 1.3% each year of the past 35 years: a loss of approximately US $100 billion[25]. Investment in anti-malaria programs will therefore generate major macroeconomic benefits. It has been estimated that while US $1 billion annually is required to fight malaria effectively, "the annual pay-off from this investment could be a US $12 billion dollars boost to the combined GDP of countries in sub-Saharan Africa". It is submitted that the establishment of an effective long-term risk monitoring system is essential in targeting preventative measures, which are required in order to reduce malarial infections.

Other economic benefits may be gained over the long-term through the development of local technical expertise and new infrastructure that will be required to implement a global strategy, which may lead to spin-offs into other areas. Considering the increasing drug costs, and the fact that treatment provides only a short-term solution to the global malaria problem, MIS can be a feasible solution to increase the effectiveness of current programs by preventing malaria and reducing its economic impact.

4.10 Conclusion

MIS is Geographic Information System integrating remote sensing technologies in the currently available systems.

MIS facilitate the integration of quantitative malaria determination and control with data obtained from maps, satellite images, and aerial photos. The integration of epidemiological data with operational and logistical data for malaria control programs will serve to strengthen both the epidemiological analysis and the planning and execution of control programs.

As seasonal meteorological forecasting becomes more reliable there users will improve the accuracy for malaria risk maps. The improved accuracy of weather forecasts and global climate change models can efficiently be employed for early malaria risk detection.

Outputs of the system are malaria assessment maps and malaria risk maps (MEWS-output) useful for government administrations, research institutions, health organizations and tourists.

Timely and high-resolution remote sensing data will provide more accurate and reliable malaria risk maps. Therefore the HI-STAR team proposes the use of space technology products as described in Chapter 3 to complement the malaria risk maps primarily based on historical and current used data.

There is a lack of professionals capable of dealing with a Malaria Early Warning System (MEWS). Therefore training and technology transfer will be integrated in the implementation strategy.

Data policies are not a major concern for the implementation of MIS.

The cost of MIS including a dissemination network can be divided into separate cost factors. Main cost drivers in the initial investment are the cost of the regional centers and the cost of the dissemination network. Main operational cost factors are depreciation costs, dissemination costs and cost of data. When high-resolution images are used, the increased cost will become the main operational cost driver.

Introduction of MIS can generate major macro-economic benefits. Considering the increasing drug costs, and the fact that treatment provides only a short-term solution to the global malaria problem, MIS can be a feasible solution to increase the effectiveness of current programs by preventing malaria and reducing its economic impact.

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5

MIS Product Dissemination

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Chapter 5 - MIS Product Dissemination

5.1 Introduction

As described in the previous chapter, one of the main challenges the Malaria Information System has to confront is the dissemination of data and information from the processing centers to the final users. In order to have the information available in an appropriate format and in time to react to the potential threat of a malaria outbreak, an efficient, cost-effective communication system needs to be established. Furthermore, access to information in a timely manner may be greatly impeded by the lack of adequate communications infrastructure in many developing nations.

This chapter identifies the elements that constitute the information dissemination chain, explains the intended information flow, and suggests possible solutions for the dissemination. The importance of the dissemination system in the framework of the entire project will be underlined, and the main attributes that characterize the system will be described. Finally, the challenges for establishing a dissemination system in developing countries will be presented, taking into account the political, legal and economic aspects.

5.2 Flow of MIS Information

The information produced by the MIS has to be distributed from the processing centers to the different elements of the health network and in some cases to the general public in affected areas. At the same time, feedback has to be sent back from the different elements to the processing centers to ensure smooth running of the system.

The elements in the malaria information chain are the following:

- MIS processing centers: Regional centers with the appropriate processing capabilities to operate MIS
- National Health Authorities or International Health Organizations acting as the central hub in the dissemination network within each country
- Regional health officers/managers in charge of distributing resources
- Population in the affected areas

The diagram in Figure 5.1 sketches the flow of information between the different elements.

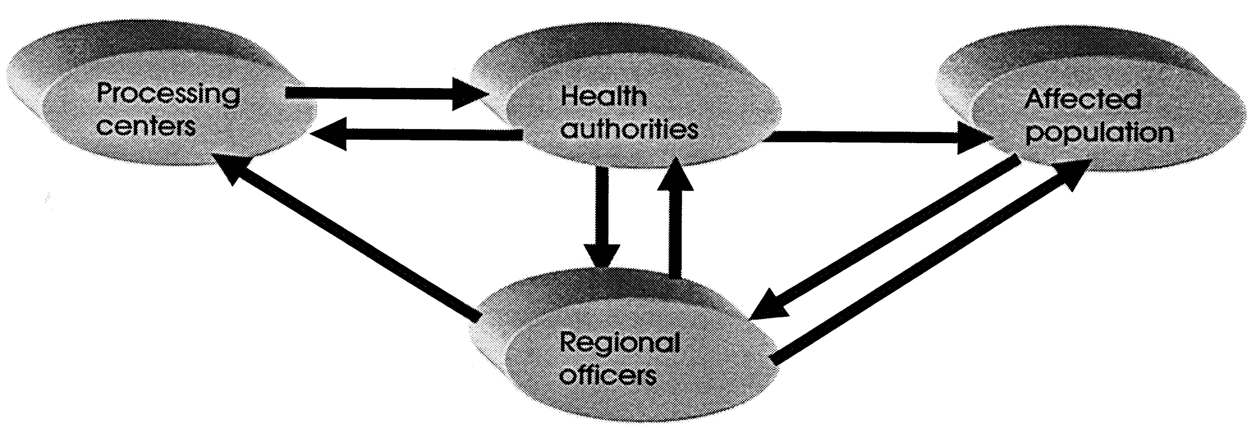

Figure 5.1 – MIS Information Flow Diagram

The MIS processing centers will produce information in the form of risk maps or assessment and warning reports. This data will be sent to the identified health authority in charge of MIS within each affected country. This authority can be either the recognized governmental health authorities or representatives from the WHO regional offices, acting as the central hub in the dissemination network. At this point the information can be classified and processed into a user-friendly format prior to being distributed to the regional health officers/managers.

The regional health officers are in charge of managing the prevention and treatment resources at the local level. They are responsible for activating the necessary mechanisms to react to the risk warnings and status reports (*e.g.* distribution of bed nets). The personnel working with the health officers have an interactive communication with the affected population, informing them and receiving information from them. These officers can be part of the national health system or personnel from the WHO, or even members of cooperating NGO's. The regional health officers should provide feedback to the national health authorities (resources management related information, status reports, statistical data, *etc.*) and directly to the MIS Processing centers (for verification, data validation, and model improvement). The health authorities will close the loop providing feedback to the MIS processing centers.

In some cases the information from the national health authorities may also need to be distributed, if possible, directly to the general population in the affected areas (*i.e.* short notice warnings, general recommendations to take preventive measures, how to act when an outbreak has already started, *etc.*). The information distributed by the national health authorities may also include general education programs and information campaigns. Examples of information that may be transmitted may include, but are not limited to:

1. Radio jingles and television playlets/drama sketches on the prevention methods employed to combat malaria (the target audience are people living in the most affected areas).
2. Radio and television information on the availability of malaria treatment centers and evacuation of areas worst affected by epidemics and in complex emergency situations.

5.3 Media Tools for Information Dissemination

This section describes potential tools that can be employed in the information dissemination process.

5.3.1 Tools for the Dissemination of MIS Information

Table 5.1 identifies the appropriate tools to collect or distribute the information for each of the main actors in the dissemination process, along with the type of information they have to handle.

Table 5.1 - Actors/Media Applications for Information Dissemination

Actors / **Tools**	**Web**	**Phone / Video Conference**	**VSAT**	**TV/Radio Broadcasting**
Processing Centers: • Delivery of MIS products (risk maps) to health authorities	X	X	X	
National health authorities: • Delivery of simplified MIS products to Regional health officers	X	X	X	
• Feedback to MIS processing centers	X	X	X	
• Communications to affected population				X
Regional health officers/managers: • Inputs to MIS and feedback to health authorities	X	X	X	

The first step is to distribute the information generated by MIS processing centers to national health authorities or international health organizations. The most efficient way to relay this information would be the use of telephone lines, either internet or fax. According to the structure defined in the previous section the information in this initial step only needs to go to one central point in each country. It is reasonable to assume that every country in the affected region has telephone capability at least in one location, giving them access to internet, telephone or fax lines. Therefore this step can be covered with existing infrastructure.

The second step, which consists of conveying the information from the national health authorities to the regional health officers, is much more challenging. In order to have easy access to all the affected population, the regional health officers have to be distributed throughout the country. In countries with an existing infrastructure which provides sufficient coverage over the entire territory the obvious choice is to make use of this resource. However, in other countries, the regional health officers may be located in remote areas lacking communications infrastructure. Should this capability be non-existent or non-available, the main alternative options would consist of:

- Satellite telephones
- Very Small Aperture Terminals (VSATs) combined with GEO satellites
- Amateur radio equipment
- Ground communications

Satellite Telephones

Satellite telephones offer multi-mode wireless communication from virtually anywhere on earth. The phones are lightweight and versatile with the capability to be hand carried, permanently or semi-permanently installed, or mounted in a vehicle/boat. Several providers like Iridium, Globalstar, or Inmarsat currently offer global satellite telephone services. Satellite phones have some coverage and time delay issues but these issues are highly dependent on the provider. Their main advantage is that they offer services in remote areas where terrestrial systems do not exist.

Very Small Aperture Terminals

Very Small Aperture Terminals are fixed satellite terminals used to provide interactive or receive-only communications. VSATs are used for a wide variety of telecommunication applications, including corporate networks, rural telecommunications, distance learning, telemedicine, disaster recovery, shipboard communications as well as transportable "fly-away" systems. VSATs are autonomous (*i.e.* solar powered), easy to use, and can be installed quickly and cost effectively. They have been in use for more than 10 years, with more than 500,000 systems operating in more than 120 countries, and they are in serial production by several corporations such as Alcatel and Hughes.

Amateur Radio Equipment

If the services of satellite communication providers are not available in some regions, reasonable choices in terms of cost could be to use amateur radio equipment. Amateur radio equipment can be very diverse offering simple two-way communication, satellite relayed communication as well as picture exchange using television. Today receivers are more sensitive and selective and our transmitters are designed to operate in continuous duty applications, holding up under adverse conditions.

Ground Communications

In those regions where none of the previous options is available or economically viable ground transport would have to be used to distribute the information.

Finally, the third step is to distribute information from the national health authorities to the affected population. The best tool to achieve this would be TV or radio broadcasting. In countries where the appropriate infrastructure is not present radio may be a cheaper option, requiring a central emitting station to distribute the signal, and at least one radio receiver per village to reach as much of the population as possible. There are some organizations like The Freeplay Foundation[1] providing, free of charge, radio receivers that work with solar energy for populations in remote areas of the developing world. A second option would be the use of satellite TV broadcasting. This would require an emitting station, satellite based transponders, and again at least one TV receiver per village to reach as much of the population as possible. To use the services of existing providers, difficulties with TV channels may arise in vying for spot broadcasting "windows", especially since it does not represent direct commercial interest for the channel.

Existing information dissemination services, like those offered by organizations such as The World Space Foundation[2] and VITA[3] (Volunteers In Technical Assistance), could also be incorporated to build the MIS product dissemination network (see Appendix D).

5.3.2 Developing Space Infrastructure

For those countries that do not have access to satellite telecommunication services, to create the necessary infrastructure to exclusively disseminate MIS information would not be a cost effective solution in the short term. However, some countries might be interested in the development of such capabilities for other purposes, and once available the infrastructure could be used for MIS data dissemination at a relatively low cost. This section outlines some of the considerations to take into account to provide satellite telecommunication capabilities for developing countries.

One solution would be to lease transponders and capacities from existing commercial telecommunication geostationary satellite operators, such as Eutelsat, Inmarsat, Arabsat, Intelsat, New Skies Networks[4] and others. The present situation of the geostationary telecommunication market seems to indicate that essential cost reductions for transponder and capacity leasing are not expected in the short term. Currently, the estimated average market cost of leasing a transponder one year is about US $1.5-3 million.

A second solution could be the use of small (400-700 kg) geostationary satellites[5,6,7] owned and operated by developing countries themselves or through regional cooperation. Such satellite systems are already in different levels of development at space agencies (*i.e* SilkSat, MedSat feasibility studies of NASA, Dialog Satellite Communication System[8,9]) as well as in industrial corporations at the level of spacecraft development. Traditionally, a scale effect means lower specific cost per transponder for spacecrafts with more transponders onboard. However, in the case of new small telecommunication satellites with 6-12 transponders (compare to 25-40 for traditional spacecraft) this effect cannot be applied, due to the large cost gap for launching such satellites in comparison with larger satellites. The small spacecrafts can be launched as piggyback with traditional commercial geostationary satellites by heavy class launch vehicles, or by middle or even small class launchers. The use of heavy class launch vehicles is less probable, because customers of main payload (commercial telecommunication operators or broadcasting companies) would demand dedicated services together with requirements of launch insurance companies, especially in light of the present state of the launch market where the offer is significantly higher than the demand. Theoretically, several of these small satellites could be launched to the same geostationary orbit slots because of the small number of transponders per spacecraft.

The second solution could be more attractive in terms of cost during the operational phase of the MIS. The estimated cost per transponder per year is about US $0.7-1 million (this includes cost of spacecraft, launch and operation). However, compared to leasing options, this solution requires a great investment from the beginning of the implementation.

5.4 Attributes of MIS Product Dissemination

Similar to other available health communication systems, the different levels of the information derived from MIS should comply with quality standards, which are summarized in by following general attributes[10] (note that not all attributes listed below are applicable to every element of the MIS dissemination chain):

- **Accuracy**:
  The content is valid and without errors of fact, interpretation, or judgment.
- **Reliability:**
  The source of the content is credible and the content itself is kept up to date.
- **Availability**:
  the content (targeted message or other information) is delivered or placed where the end users can access it. (Placement varies according to audience, message complexity, and purpose, ranging from interpersonal and social networks to billboards and mass transit signs to prime time TV or radio, to public kiosk (print or electronic), to Internet.

- **Evidence Base:**
  Relevant scientific evidence that has undergone comprehensive review and rigorous analysis to formulate practice guidelines, performance measures, review criteria, and technology assessments for health applications.
- **Balance**:
  Where appropriate, the content presents the benefits and risks of potential actions or recognizes different and valid perspectives on the issues.
- **Consistency**:
  The content remains internally consistent over time and also is consistent with information from other sources.
- **Reach:**
  The content reaches or is available to the largest possible number of people in the target population.
- **Repetition:**
  The delivery of and/or access to the content is continued or repeated over time, both to reinforce the impact with a given audience and to reach new generations.
- **Timelines:**
  The content is provided or available when the audience is most receptive to, or in need of, the specific information.
- **Understandability:**
  The reading or language level and format (including multimedia) are appropriate for the specific audience
- **Cultural Competence**:
  The design, implementation and evaluation process should account for special issues for select population groups (for example, ethnic, racial, and linguistic) and also educational levels and disability.

5.5 Overview of Existing Health Information Systems

This section presents an overview on how information technology is used in national health care systems to create 'health information systems'[11,12]. Due to poor infrastructure advancement in most developing countries, the model presented here exists only at top-level decision-making centers, i.e. the major health institutions. The health information systems model consists of the following components:

- **Information Storage:**
  This component makes use of a database stored in computer servers. It is an archive of information gathered from multiple sources and stored under a unified scheme at a single site. These sites are in existence in all the major public/community health institutions (i.e. educational, psychiatric/mental health institutions). The database provides the user with a consolidated interface to data, thereby making decision support queries easier to write.

- **Information Retrieval:**
  Information resident in the database server is used in decision support systems and clinical decision-making. This information is presented in an interactive computer software based mode.

- **Information Broadcast:**
  Information broadcast is mainly done through mass media campaigns. However, one-dimensional approaches to health promotion, such as reliance on mass media campaigns or other single-component communications, have been shown to be insufficient to achieve program goals.

Successful health promotion efforts rely increasingly on multidimensional interventions to reach diverse audiences about complex health concerns. Communication is integrated from

the beginning with other components, such as community-based programs, policy changes, and improvements in services and the health delivery system.

5.6 Challenges and Opportunities in the Establishment of a Dissemination System

When developing a dissemination system to combat malaria in developing countries, a number of challenges should be taken into consideration to ensure smooth implementation or integration of such a system in a given region. This section briefly introduces some of these issues and describes potential solutions. In the end, the goal is to ensure that risks maps or other information useful to the end user are accessible in an efficient and timely manner.

Without access to information, regions affected by malaria enter a vicious cycle, whereby they are constantly in response mode, treating outbreaks rather than attempting to forecast and prevent them. Unfortunately, access to information in a timely manner is currently greatly impeded by the lack of adequate communications infrastructure in many developing nations.

The investment associated with creating such a dissemination system will be less costly in developing nations that already have receiving stations or adequate ground infrastructure. The examples of India, Indonesia, Nigeria and Kenya are presented as case studies in Chapter 7. India and Indonesia are space-faring developing nations that already have infrastructures with telecommunication capability and the capacity of receiving and interpreting data. In such a situation, the overall cost of implementing MIS should be fairly minimal.

Nigeria does have a ground station and has good television and telephony systems. Therefore, dissemination of information through these means is possible. In the case Kenya however, the situation is somewhat different. Out of the four countries, Kenya definitely requires the highest investment, as it does not possess a good communication infrastructure. An analysis of how MIS could provide benefits in these countries is presented in Chapter 7.

Convincing governments to invest in the use of existing telecommunication networks and appropriate ground infrastructure also presents a challenge. Political and economic aspects are directly linked to the success of a dissemination network. Decision-makers need to understand how investment in technology today will help in saving lives and money over the longer-term. Political buy-in, as well as political and economic stability, are therefore essential to the success of the MIS product dissemination. Obtaining government support can only be achieved through strong lobbying or education efforts, demonstrating the usefulness, cost-effectiveness and potential benefits and applications to be gained using a dissemination system.

To reduce the costs associated with the establishment of a dissemination system, existing infrastructures should be used to a maximum. For example, the United Nations currently has education centers located in India, Nigeria and Morocco that could potentially be used for education and outreach.

Pooling resources should also be considered. Section 5.3 mentioned the examples of MedSat and SilkSat that will provide a cost-effective mean of accessing small telecommunication satellites. By pooling the resources of national or regional companies in several countries, a small GEO satellite can successfully be established. In 2004, a new regional satellite organization by the name of RASCOM will provide satellite telecommunications for African countries on a commercial basis. This should facilitate access to satellite communications in Africa.

The establishment of a dissemination network may lead to a wide variety of other benefits for developing nations, in particular in the tele-education or tele-medicine fields. Education of the general population might include topics such as health care, hygiene, as well as prevention and identification of malaria. Furthermore, access to highly qualified professionals for

diagnosing and monitoring patients through audio/visual means and quick efficient dissemination of potential weather hazards are also valuable examples of such applications

5.7 Legal Aspects of Telecommunication Systems Established in Developing Countries

The regulatory framework for ground or satellite communications in Africa and Asia may vary significantly from one country to another. Generally, the African and Asian telecommunications markets are notably less liberalized than the Western countries. Therefore, when using telecommunications in Africa and Asia, different regulatory and policy issues may arise.

The telecommunication market today is still dominated by incumbent, state-owned carriers benefiting from a monopoly. Only 17 of the 44 African International Telecommunications Union members have gone through a privatization process of their telecommunication sector. In other countries, the market is protected with ownership limitations, i.e. foreign companies can own only a maximum share of a telecommunication company. In these countries, this monopoly will limit the choice of ground networks available and of mobile communications providers for the provision of the MIS services.

The telecommunication sector might also be affected by other protective regulations. For example, some African countries impose high customs fees on satellite communications receiver's or/and excessive licensing fees for their use, thus, increasing the cost of communications, whereas in an open market, competition lowers the cost. This element should be taken into consideration when anticipating the cost of the MIS services and when choosing a type of telecommunication for data distribution.

Access to telecommunications networks for services is regulated by the Annex of the General Agreement on Trade and Services (1993). On the basis of this document, all telecommunications-based service providers shall have access to the networks on the same basis. Therefore provision of MIS should be facilitated.

5.8 Cost of the System

The preceding sections show that a dissemination system can have many appearances. It can differ from complete satellite systems to broadcasting medical bulletins by radio or television. A general cost estimation of the MIS product dissemination is therefore difficult to provide. However, the chosen dissemination network is one of the main cost drivers in the initial investment and also the main cost driver in the MIS operation (i.e. direct dissemination cost and depreciation cost related to the system). A cost effective dissemination system is therefore a key issue in the MIS design and can make the difference between success and failure. In order to minimize costs, MIS should use, to the largest extent possible, locally existing communication systems and add communication links compatible with local systems.

The best way to estimate the cost of a dissemination network is by pricing the hardware and training of personnel. A Rough Order of Magnitude (ROM) estimation for a low cost option like a satellite telephone (including shipping expenses) is US $700 plus another US $1000 for training of local personnel. The operation costs are mainly the satellite telephone cost at US $1/minute, for an approximate US $500 per dissemination point per year. As a large number of dissemination points might be needed for an effective MIS warning system, these costs can become the major operation expense in a MIS program.
If the choice is to use VSAT, today's (2002) average price per VSAT is about US $2000.

New developments in satellite communications, as described in previous sections of this chapter, may reduce the cost of future MIS dissemination systems. It is therefore recommended to monitor the capabilities of new developments in satellite communications on

a regular basis in order to implement them as soon as they are more cost-effective than current systems.

When a dissemination network is in place, the network can also be used for on-site data collection. This is an important spin-in possibility for the MIS itself as already discussed in this chapter. Possibilities for low-cost gathering of information on malaria outbreaks and/or meteorological data should be already considered during build-up of the dissemination system. In this way the MIS has maximum benefits from the investment in the relatively expensive communication hardware.

5.9 Conclusions

As demonstrated in this chapter, there are various advantages to having a dissemination network. Not only would a dissemination network be useful in combating malaria, providing timely information to decision making authorities and aid agencies on the ground, it could also create an infrastructure with a variety of other applications that would further enhance health improvement in developing countries.

The overall benefits and objectives of a dissemination system would be to:

- Ensure information transfer (malaria maps/information on areas affected) in a timely manner; providing early warning to authorities of the potential of malaria outbreaks and thus providing them with the opportunity to allocate resources for these higher risk areas
- Improve the quality of treatment in remote areas affected by malaria by linking medical staff in the regions with professionals around the world through use of audio/video conferencing capability
- Educate the general population and medical personnel on health care and hygiene in the affected regions through tele-education means
- Inform the general population of potential epidemical circumstances, thus potentially encouraging them to modify their behavior
- Integrate telecommunication/tele-education and broadcasting systems, especially in countries and regions with less developed ground telecommunications

The cost to achieve these goals would depend on the solution selected. The first option is to use the existing or foreseen infrastructures, including the capacities of commercial satellite telecommunication providers such as Eutelsat, Intelsat, Arabsat, Inmarsat, *etc.* Other option is to use portable autonomous terminals (Very Small Aperture Terminals). Another alternative is to operate a small GEO satellite through a collaborative partnership at national or regional level.

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6

Integration of MIS with Existing Programs

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Chapter 6 - Integration of MIS with Existing Programs

Chapters 3, 4 and 5 have extensively demonstrated how space technology could fulfill the technical requirements in the fight against malaria. However, as useful as space technology can be, political, legal and financial impacts must be addressed. In addition, funding, promotion and education challenges stemming from the gap between the health and space worlds must be taken into account as well.

This chapter will provide an overview of major international programs and initiatives that are currently combating malaria and vector-borne diseases in general. It will then define how to address the impacts and challenges mentioned above, proposing a global strategy integrating MIS and other space technologies into current efforts.

6.1 Major International Programs and Initiatives

In order to determine how space technologies can help fight malaria, it is first necessary to describe the international programs and initiatives that are involved in anti-malaria activities. The following section provides a brief description of some of the major players at the forefront of the international battle against malaria.

6.1.1 Roll Back Malaria (RBM)

The Roll Back Malaria initiative is based on a global partnership and aims at halving the world's burden of malaria by 2010[1]. It was initiated in November 1998 by the World Health Organization (whose headquarters hosts the Secretariat) together with the World Bank, the United Nations Development Program (UNDP) and the United Nations Children's Fund (UNICEF). Later, other participants joined the initiative, including governments of malaria-affected countries, donor agencies, non-governmental organizations, international private sector representatives and research groups. Over 90 multilateral, bilateral, non-governmental and private sector organizations and 24 African and Asian countries are active members of the RBM initiative (see Figure 6-1).

RBM attempts to take into consideration the distinct priorities of particular countries, who implement the initiative independently. Nevertheless, cooperation between countries is encouraged. RBM's approach is horizontal, meaning that it aims to combat malaria through the improvement of the entire health sector.

Roll Back Malaria uses the following tools to ensure that its interventions are adopted on a wide scale:

- Health system strengthening and improvement
- Community mobilization
- Partnerships between governments, civil society and the private sector to find ways to provide better use of resources

RBM also promotes four main strategies:

- Prompt access to treatment
- Use of insecticide-treated mosquito nets (ITNs)
- Prevention and control of malaria in pregnant women
- Malaria epidemic and emergency response

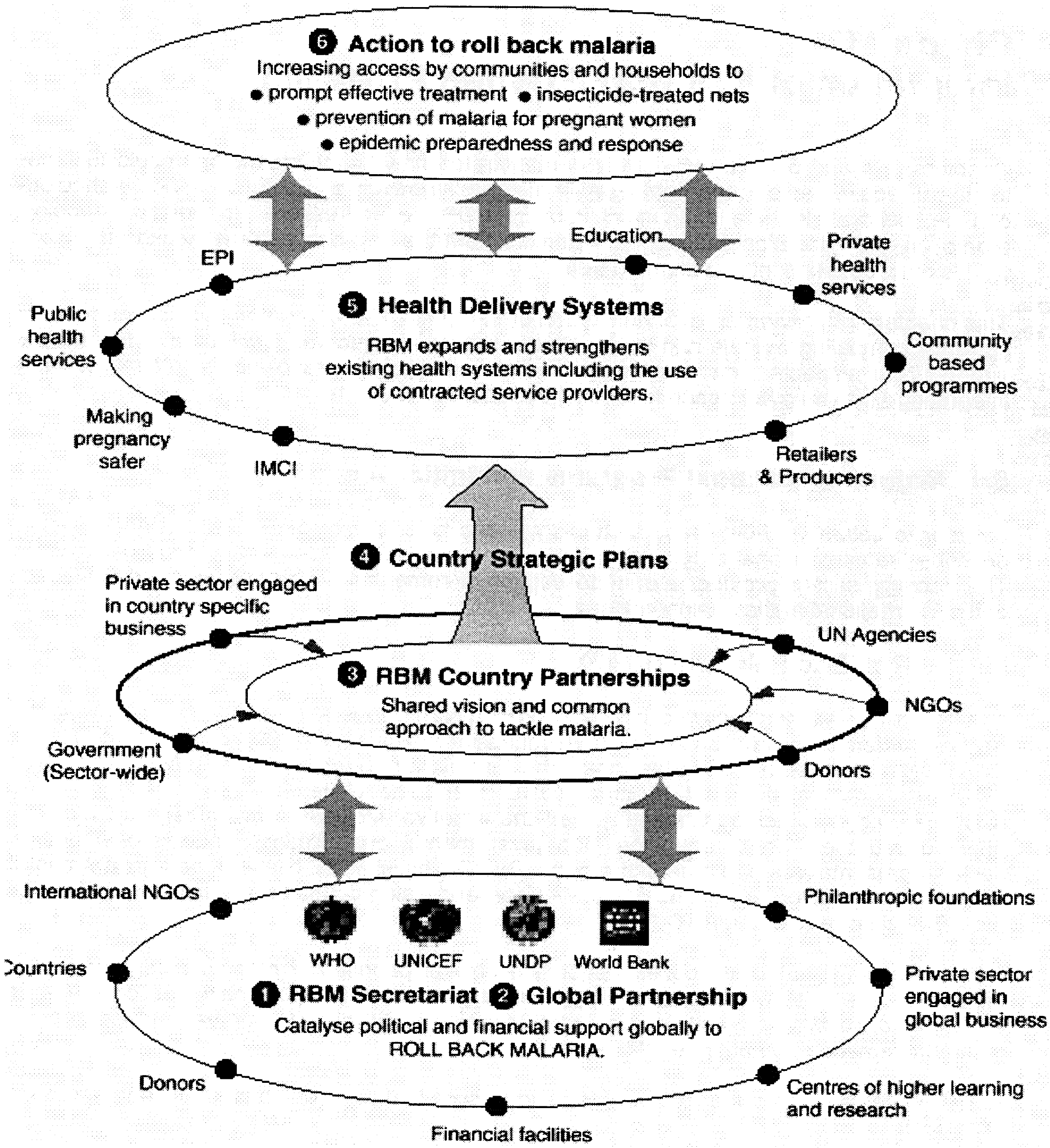

Figure 6-1 - RBM Organizational Chart[2]

Since 2000, the amount of money received from the international community has been less then US $100 million per year (refer to Appendix H.1 for more details). It is estimated that an additional US $500 million of global funding over the next 5 years is still needed to fill budgetary gaps resulting from scaled-up strategies in sub-Saharan Africa.

6.1.2 Multilateral Initiative on Malaria (MIM)

The Multilateral Initiative on Malaria (MIM) is an alliance of organizations and individuals aiming to maximize the impact of scientific research on malaria in Africa through promoting capacity building and facilitating global collaboration and coordination. MIM was established in 1997 with the goal of strengthening the capability of malaria endemic countries, mainly in sub-Saharan Africa. The program also aims to support the research-control interface to ensure that research findings yield practical health benefits. These goals are achieved through raising international public awareness of the problem of malaria, promoting global communication and cooperation, developing sustainable malaria research capacity in Africa and ensuring that research findings are applied to malaria treatment and control.[3] The end clients in this case are defined as the research organizations in endemic countries, which use research results to educate, train and conduct further research.

In terms of funding, contributions of approximately US $100 million are divided among MIM's programs, currently eighteen. MIM currently spends approximately US $1.2 million for research, US $400,000 for Secretariat costs and US $7.0 million (over 5 years) on MR4, a program designed to disseminate information about malaria through various media and major conferences[4]. MIM is supported by the World Health Organization's Roll Back Malaria initiative.

6.1.3 Special Program for Research and Training in Tropical Diseases (TDR)

TDR is an independent global program of scientific collaboration that aims to help coordinate, support and influence global efforts to combat a portfolio of major diseases of the poor and disadvantaged. It focuses on several vector-borne diseases in tropical endemic countries. TDR's objectives are the following:[5]

- To improve existing and develop new approaches for preventing, diagnosing, treating, and controlling neglected infectious diseases which are applicable, acceptable and affordable by developing endemic countries, which can be readily integrated into the health services of these countries, and which focus on the health problems of the poor
- To strengthen the capacity of developing endemic countries to undertake the research required for developing and implementing these new and improved disease control approaches

TDR's approved budget for 2002-2003 is US $95 million. The program is supported by WHO, UNDP, World Bank, 22 governments/member states and 8 other foundations and agencies. TDR allocates its resources to four different research fields: Basic and Strategic Research (14%), Intervention Development and Implementation Research (23%), Product Research and Development (31%) and Research Capability Strengthening (32%).[6] 51% of TDR funds are used for the prevention and control of Malaria.[7]

6.2 General Analysis of Program Needs

Through the analysis of the above programs various challenges have been identifies. A number of factors are critical in order to ensure the success of an anti-malaria campaign. The following briefly enumerates some of these factors.

6.2.1 Risk Monitoring

As demonstrated in Chapter 2, there exists a strong correlation between certain factors, such as the nature of land use, climate change, breakdowns in health services, armed conflict as well as poverty[8] and increases in the risk of diseases like malaria. As a result, it is possible to implement monitoring techniques that can help in preventing a malaria outbreak before it occurs. One means of risk monitoring is through the use of Earth observation. One example of this is the use of Landsat satellite imaging in Gambia to predict high-risk malaria areas up to four months in advance[9]. Nevertheless, often the success of risk monitoring is only as effective as the ability to transmit key information to those who are capable of implementing preventative measures. A risk monitor effort would therefore benefit from MIS.

6.2.2 Communications Infrastructure

As suggested above, communications infrastructure is essential to ensure that public officials as well as those in charge of prevention and treatment are aware of potential threats to the population. While sometimes this is taken for granted in developed nations, in many developing countries lower level healthcare workers lack sufficient means for alerting central authorities about potential outbreaks. The result is that coordinated responses to threats are delayed. Therefore, these gaps in communications limit the effectiveness of international disease control programs. Further, this problem has the additional effect of leaving cases unrecorded and unreported[10]. Discussions with Dr. Teklehaimanot[11], a malaria expert from the WHO, indicated that better communications infrastructure would greatly assist organizations on the ground to target high-risk malaria areas. This would allow for timely allocation of human and material resources for preventative measures and the dispensing of treatment to people on the ground.

6.2.3 Availability of Prevention Measures

If high-risk areas are identified in advance, it is possible to implement preventative measures capable of protecting local populations. One common preventative measure is the use of ITNs. Studies have indicated that cases of malaria amongst children can be decreased by 50% if those children are covered by ITNs while they sleep[12]. Another common preventative measure is the use of insecticides like DDT (DicholoroDiphenylTricholoroethane), a measure that has been a cost-effective means of controlling malaria-carrying mosquitoes in South Africa and Ethiopia[13]. Therefore, preventative measures do exist that can help reduce the risk of malarial infection.

6.2.4 Carefully Tailored Strategies for Specific Areas

International strategies must be well suited to the region where they are intended to be implemented. This requires a good understanding of the realities and local resources in a given area. If there is a discrepancy between an overall program's strategy and realities on the ground, it is unlikely that the program will succeed. RBM's policy mandating domestic implementation of its international program is mindful of this necessity. The choice of malaria treatment is another example of how strategies must be tailored. Dispensing medication to infected populations has proven to be an increasing challenge in recent years because common malaria parasites have developed a resistance to commonly used anti-malaria

drugs. According to Kamini Mendis, WHO adviser on treatment access, "the current drugs used to treat malaria are no longer working."[14] Nevertheless, traditional treatments are still effective in certain places. For example, while in Asia and South America, malaria parasites have a high resistance to common anti-malarial drugs such as chloroquine, the drug is still producing satisfactory results in Central America[14]. Therefore, treatment strategies must be tailored to respond to the specific needs of particular regions.

6.2.5 Healthcare Infrastructure, Research Facilities and Qualified Personnel

Another prerequisite for the effective implementation of a campaign against malaria is the availability of an infrastructure capable of coping with health problems. In developing countries, many national health departments lack the equipment required to conduct adequate risk monitoring, such as fax machines, computers and integrated data systems[15]. An effective anti-malarial campaign also requires access to labs and training centers to research disease prevention and treatments as well as to train a new generation of scientists[16]. Both of these essentials are lacking in certain developing nations. In terms of research facilities, WHO has reported that 60% of laboratory equipment in developing countries is either outdated or not functioning. Without functioning equipment, proper diagnosis of malaria cannot be conducted[17]. Further, many research facilities are staffed by unqualified personnel. One reason for this is that poor salaries and working conditions drive many qualified healthcare workers to other countries in search of work[17].

6.2.6 Social Coordination and Education

Any effective anti-malaria campaign must have a means of employing its strategy on the ground. This necessarily involves social coordination and education among those at risk of contracting the disease. In terms of information, many people at risk do not know that ITNs are capable of both repelling and killing mosquitoes that carry malaria. In some countries health services must compete with traditional medical practitioners to provide the population accurate information. Professor Alphonsus B. C. Nwosu, Nigeria's Minister of Health, recently noted that sometimes traditional medical practitioners in his country provide scientifically unproven treatments, which do not lessen the risk of malaria.[18]

6.2.7 International Financial Support

Cost constraints are another major challenge faced by anti-malaria programs. Despite the fact that States donate money to international programs and that there are many organizations that conduct fundraising efforts, the amounts received are still insufficient. Maintaining continuity of funding over time is also a major challenge faced by anti-malaria programs. Often there is fluctuation in the level of funding that programs are able to raise from one year to the other. For instance, the TDR program raises from US $80 to US $100 million per year, depending on the level of donations. A lack of donations in a given year may have dramatic effects upon the success of a program. For instance in Tanzania, there was enough funding to distribute bed nets over a 5-year period[19]. The success of the program contributed to decrease the number of malaria cases, but in the meantime the population became less immune because they were not exposed to the disease as much as they had been in the past. When support for the program suddenly stopped, the now vulnerable population was left with no protection before the threat of malaria was completely diminished. Increasing drug costs also make treating malaria more difficult. To illustrate this point, it is useful to consider the cost of malaria drugs. While conventional drugs like chloroquine or sulfadox cost six to seven cents per adult patient, more effective treatments like ACTs (Artemisnin-based Combination Therapies) cost US $1.50 to US $2.50 per patient[20]. This increase in cost can be a major burden to developing countries. Other costs include the delivery of nets and even the retention of qualified health care practitioners who are driven away by higher salaries elsewhere.

6.2.8 Political Will and Understanding the Utility of Available Technology

International and domestic political will are prerequisites for an effective anti-malaria program. Political will is a critical factor in providing many of the program needs listed above, because it is vital to acquiring the financial resources required to meet program needs. Programs can stimulate international political will by pointing out that malaria is a global problem capable of spreading to developing countries as well as those that have traditionally grappled with the disease. Naturally, programs can also appeal to the international community on humanitarian grounds. Domestic political will is also essential in order to effectively implement anti-malaria strategies on the ground.

A final program requirement is the need for policy makers to understand the utility of certain technologies in helping them obtain their goals. Enhancing policymakers' understanding of the utility of technology is an important factor when proposals are searching for funds to support particular projects[21].

6.2.9 Favorable Laws and Policies

The need for favorable laws and policies at the international and national level is an extension of political will. At the international level, campaigns against malaria can be delayed by international policies that restrict or do not endorse the actions required to effectively implement anti-malaria strategies. This sometimes involves the granting of resources for foreign aid with certain conditions attached. For example, the World Bank gives countries like Eritrea and Mozambique resources to fight malaria on condition that the insecticide DDT is not used.[22] Also, US foreign aid laws prohibit countries from imposing user fees for primary healthcare in programs funded by American contributions to the World Bank.[23] Whether warranted or not, conditions such as these put constraints on anti-malaria strategies. Other constraints include the endorsement of anti-malaria treatments by the WHO and powerful countries.[24] Other policy issues include strategies recommended by international organizations. For instance, while the World Bank has encouraged an horizontal approach to health care (i.e. emphasizing overall health sector improvement), certain countries seek to implement vertical strategies which attempt to combat particular health threats. As a result, discrepancies between national and international policies can lead to problems in the implementation process. At a national level, campaigns in the past have been burdened by policies such as sales taxes on bednets. Fortunately, five African countries (Cote d'Ivoire, Nigeria, Tanzania, Uganda and Zambia) have recently reduced or abolished taxes on nets, lowering their price.[25]

6.2.10 Measurements of Program Effectiveness

Measurements of program success help identify areas where program modifications are required and also aid in ensuring accountability. However, measuring program effectiveness is often complex because progress is sometimes difficult to ascertain. RBM has already developed a precise framework for monitoring progress and evaluating outcomes, with imposed global and country-specific indicators.[26] Unfortunately, financial resources are not often allocated for follow-up of effectiveness measurements.

6.3 Addressing Program Needs with MIS and Space Technology

The goal of this report is to demonstrate how space technology can be effectively used to fight malaria. While the needs enumerated above cannot all be addressed by space technology, it must be recognized that space technology can be leveraged in order to enhance risk monitoring, help target prevention strategies and provide telecommunications services essential for timely treatment. In order to achieve this, programs need to commit to enhancing research capabilities and promote their cause both internationally and nationally to generate political will and policies favoring the use of space technology in combating malaria. After considering program needs, it is now necessary to determine which can be addressed by MIS. They include:

- Risk monitoring
- Communications
- Targeted preventative measures
- More efficient management of resources required for treatment

However, it must be understood that space technology and MIS are only tools that can help combat malaria in a more efficient manner. Space technology alone will not be able to address all program needs.

In addition, a program incorporating space technology and MIS also has particular needs in common with general anti-malaria programs, notably the need for:

- International financial support
- Political backing
- Demonstrating the utility of the relevant technology

6.4 Programs Using Space Technology

If the utility of MIS and space technologies is more fully understood by the international community, political will and international financial support may be forthcoming. This section demonstrates how space technology has actually been applied to combat malaria and other vector-borne diseases. These programs include initiatives undertaken over the last two decades that incorporate the use of remote sensing data, GIS and satellite telecommunications. Section 6.6 addresses in more detail how MIS in particular can complement existing malaria programs.

6.4.1 Mapping Malaria Risk in Africa (MARA)

MARA was started in 1995 to try to fill an information gap for combating malaria on the African continent in order to identify high risk areas and facilitate adequate timing for anti-malaria measures i.e. distributing bednets. MARA produces risk maps, disseminates information to decision makers, health departments and funding organizations as well as developing GIS capabilities in Africa.

The maps produced by MARA are based on models for distribution, seasonality and transmission intensity. These maps contain information on distribution, endemic/epidemic areas, duration of transmission risk season and malaria transmission intensity. They are combined with population data and identify groups at risk of contracting malaria.

The distribution model and seasonal model are theoretical models based on long term climate data and have a resolution of 5x5 km. These are based on ground based weather data collected over the last 60 years. Therefore, they do not show actual malaria cases but show the theoretical suitability of the local climate, and thus the potential distribution of malaria in an average year. An example of a distribution map is shown in Figure 6.2. Apart from distribution maps, the distribution model is used to provide maps of endemic and epidemic areas, which again is combined with population data to calculate the number of people living in these areas. The seasonal model shows the potential duration, onset and end of malaria transmission season in an average year. Both models have the drawback that they are static models that do not take into account the substantial changes in climatic conditions from one year to another. Neither outbreaks of malaria caused by abnormal temperatures and/or rainfall nor the effects of malaria control programs will therefore be included in these maps.

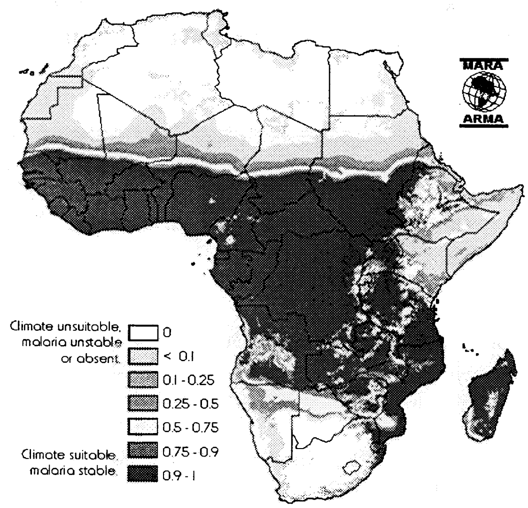

Figure 6.2 - MARA Map for Malaria Distribution

(Source: www.mara.org.za)

The transmission intensity models are statistical/spatial models based on empirical malaria prevalence data analyzed against different environmental factors such as climate, altitude, vegetation cover and agro-ecological zones. Based on the models, the level of prevalence in areas where no malaria data is collected is then predicted. These models use remotely sensed rainfall estimates from Meteosat, NDVI data and consider using AVHRR for surface temperature.

The maps are made available as posters, books and in digital format and are freely downloadable from the MARA website (www.mara.org.za). Information from MARA has also been used to time the transmission of malaria information to the public in countries such as Tanzania. In addition to the collection and dissemination of information, MARA works on developing GIS capabilities among the staff from different malaria control programs. A remaining challenge for MARA is the dissemination of products and GIS skills that can contribute to the success of organizations like MIM and RBM.

The MARA project is based on the collaboration of five regional centres at already existing institutions throughout Africa, coordinated by the MARA centre in South Africa. These various centres are responsible for data collection and GIS training for their respective regions and mostly work autonomously. The MARA staff consists of approximately 15 part-time employees.

Since its inception, MARA has been funded by different local and international organizations, such as TDR, the International Development Research Center (IDRC), MIM and RBM. MARA spends approximately US $100,000 per year on data collection, meetings, workshops and a small part of the salaries. African organisations participating in MARA cover the majority of employee salaries and contribute more than international organizations.

Program needs addressed by MARA:

- Risk monitoring
- Targeted preventative measures
- More efficient management of resources required for treatment

6.4.2 Charter for Health Application of Aerospace Related Technologies (CHAART)

Charter for Health Application of Aerospace Related Technologies (CHAART) was initiated in 1995 by NASA Headquarters' Life and Biomedical Sciences and Application Division. CHAART grew out of the knowledge acquired during the former NASA Global Monitoring and Human Health (GMHH) program, which was launched in 1985. Its mission is to promote the application of remote sensing, GIS and related technologies to issue of human health. CHAART's objectives are to:[27]

- Expand the use of aerospace and information technologies by the human health community through training, outreach, education, applied research, and direct transfer of proven technologies and knowledge to research/control agencies and universities
- Assist health investigators in the utilization of CHAART capabilities to achieve the goals and objectives of their research
- Assess existing and planned aerospace-related technologies for use in health research, and encourage appropriate developments for this application

To date CHAART is conducting several research projects on the application of remote sensing to vector borne diseases, seven of them specifically on malaria in the following countries: Brazil, USA, Kenya, Mali, Mexico, Peru.

To illustrate the potential applications of CHAART, it is useful to consider the first experiment of GMHH, which was conducted in the California rice field area. The experiment demonstrated that RS and GIS technologies can be used to identify high mosquito-producing rice fields with greater than 90% accuracy. These high-producing fields could be identified two months prior to peak mosquito production using three different approaches, providing a method for early warning. Therefore, these approaches could be used to direct mosquito control measures in California, or, with modification, in other rice-growing regions of the world where malaria transmission remains a human health problem. Then the approach was extended to a malaria-endemic area in southern Chiapas, Mexico. NASA's Ames Research Center, in collaboration with universities and health agency scientists, conducted research on the ecology of the anopheles albimanus mosquito, a key vector of human malaria in the coastal areas of southern Chiapas, Mexico. The method was able to correctly distinguish villages with high and low mosquito abundance.

These studies highlight that the proposed method, which integrates remotely sensed data and GIS capabilities to identify villages with high vector-human contact risk, provides a promising tool for malaria surveillance programs. In general, this approach could be applied to other diseases in areas where the landscape variables critical to disease transmission are known, and these elements can be detected using remote sensing.

The major program need addressed by CHAART is risk monitoring.

6.4.3 SatelLife

SatelLife is a non-governmental and non-for-profit organization based in Boston, MA, USA. Created in 1989 by the International Physicians for the Prevention of Nuclear War, the objective of this organization was to use LEO Satellites to improve the communication of the medical information between the North and South of Africa. Funded by the IDRC, SatelLife created a global communication Network called HealthNet, which is in existence. HealthNet is intended to promote communication between health professionals across the globe through electronic conferences and newsletters or publications. SatelLife works with many partners and donors such as ministries of health, medical schools, medical libraries, and other health facilities to build locally owned and managed HealthNet networks.

In Ghana, HealthNet links health professionals from Navrongo and Accra, two cities 1,000 kilometers apart. Thanks to a donation from NEC Corporation (a portable Mlink 5000 ground station), scientists on the project do not have to travel in order to share data, report findings to other health officials or access information from related malaria initiatives. Today, HealthNet works thanks to two LEO Satellites (HealthSat I and HealthSat II), many ground stations, a network of computers and a radio operator system. It is functional anywhere in the world, no matter how remote. HealthNet covers currently numerous African countries: Botswana, Burkina, Cameroon, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Kenya, Malawi, Mali, Mozambique, Nigeria, South Africa, Senegal, Sierra Leone, Sudan, Tanzania, Uganda, Zaïre, Zimbabwe.

The strengths of HealthNet lie in its affordability and ease of use. It is currently used by approximately 19,500 healthcare workers in more than 150 countries (23 African countries).[28]

Program needs addressed by SatelLife:

- Communications
- Targeted preventative measures

6.4.4 Healthy Planet

Healthy Planet is a NASA Earth Science Enterprise and a Goddard Space Flight Center program. The goal of the program is to apply the space-based remote sensing data and technologies to better understand the links between human health and the environment, weather and climate. The program also develops new tools for health-related surveillance and early warning systems. Healthy Planet is conducting many projects dealing with Rift Valley fever, malaria, asthma, air pollution, urban heat, West Nile viruses, meningitis, ebola, cholera, St Louis encephalitis, filariasis and bartonelosis. They are also developing a kind of "collaboratory" where scientists and professionals can share their knowledge in order to help decision-makers address important health environment related issues.[29]

Among the current projects the Mekong Malaria and Filariasis Project and the Regional Health-Environment Alliance are the most relevant to this report. The goal of the Mekong Malaria and Filariasis Project is to identify the potential sites for larvicide and insecticide applications by mapping the habitats of major vector species in order to develop a malaria transmission model to predict the occurrence of malaria and its transmission intensity. The Regional Health-Environment Alliance is an organization formed under the joint leadership of the Pennsylvania State University and NASA. The goals of the Alliance are:[30]

- To provide information on the spread of infectious diseases in order to predict and avoid adverse health outcomes, focusing on West Nile virus and lyme disease
- To identify, inform, and manage the risk of environment-related adverse health outcomes by forecasting using powerful decision-support and information management technologies
- To address environment/health-linked issues, including severe weather impacts, health risks of air and water pollution, contamination pathways of water and food-borne illnesses, bio-terrorism, and infectious disease transmission

Program needs addressed by Healthy Planet:

- Risk monitoring
- Targeted preventative measures

6.4.5 EMERCASE : a Space Surveillance of Epidemics Consortium (S2E) Initiative

Space Surveillance of Epidemics (S2E) is a French consortium that developed a common integrated approach in public health by prediction and management of health risk. The goals of S2E are to "open by the deep analysis of health environment relationships a new field for early warning operational systems able to alert and predict the geographical extension of epidemics."[31] It started in 1999 and has been applied in various regions of the world, namely Africa, South America and Asia and to different vector born diseases.

The French organizations involved are the Centre National d'Etudes Spatiales (CNES), the Agronomic Research Institute (INRA), Veterinary School of Lyon and Pasteur Institute, in collaboration with scientific laboratories (CIRAD, CEA, IRD, Universities) and industrial partners (EADS-MS2I, SOGREAH, SPOTIMAGES and BRGM). They also cooperate with Senegalese governmental organizations.

The work of this consortium is based on three complementary pillars:

- Health Information Systems (epidemiological networks), real-time early warning, information transfer management
- Bio-mathematical modeling of epidemic dynamics (transportation processes, pathogens, vectors, hosts and physical & socio-ecological environment)
- Remote sensing to measure cofactors like vegetation and meteorology

The EMERCASE program which deals with Rift Valley fever in Senegal, is the first S2E application. The Rift Valley fever is similar to malaria. It is a haemoragic fever causing mortality in human and animals populations. It has high potential extension risk to the mediterranean zone. Financial information concerning the program is unfortunaly not accessibly to the public at this time.

EMERCASE makes use of a Wide Information System consisting of remote sensing, environmental data collection and analysis, information management, storage and distribution to all participants. The program combines remote sensing data with a epidemic sentinel warning network. The sentinels are personnel of the Senegalese cattle-rearing operators. They collect data regarding rift valley fever cases using Palm OS workstations that provide power and telecommunication independence. This data is combined in a database with remote sensing data in order to more accurately assess the risk of rift valley fever. Mobile teams of veterinary inspectors, equipped with PC-based workstations, can have access to the database and directly help the cattle-rearers if needed (see Figure 6.3). Space technology is therefore used for remote sensing and telecommunications, which allow for the dissemination of information on potential epidemics.

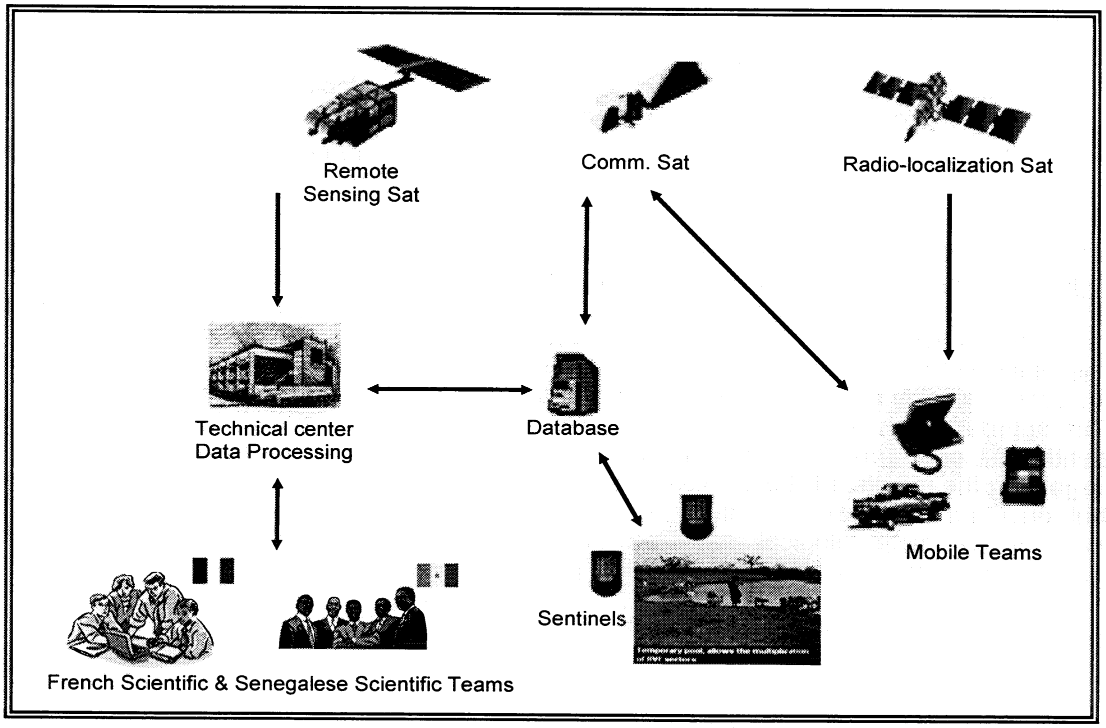

Figure 6.3 - EMERCASE Network[32]

Program needs addressed by EMERCASE:

- Risk monitoring
- Communications
- Targeted preventative measures

6.4.6 MALSAT

MALSAT is a research group of the Liverpool School of Tropical Medicine in the UK. The aims of this group are "to assess the utility of Remote Sensing and GIS for direct use in malaria control planning, and to explore the options for the development of Environmental Information Systems which can form a component part in improved malaria control operations".[33] The bulk of the work of MALSAT has been centered on malaria in sub-Saharan Africa, but the technologies are applicable to other vector-borne diseases, and in general to any disease that has a response to climatic conditions. In fact, the research activities of MALSAT have recently been extended and applied for example to the study of meningitis in Africa. Since 1995 MALSAT has also been involved in a number of initiatives in Africa to provide training to workers from health, environment and climate sectors in the use of GIS and Remote Sensing techniques.

MALSAT cooperates with different Health Organizations and has completed projects for WHO's Tropical Disease Research Division, Medicins-Sans-Frontieres (Holland), the UK's Medical Research Council, UK's Department for International Development and the US National Oceanographic and Atmospheric Administration's Office of Global Programs. MALSAT is funded by the UK Department for International Development (DFID) through the Malaria Knowledge Program of the Liverpool School of Tropical Medicine.

MALSAT current work includes:

- The use of Environmental Information Systems in developing and improving malaria control strategies in sub-Saharan Africa
- Forecasting meningitis epidemics in Africa, a new 3 year project to develop a climate-driven model for predicting outbreaks of meningococcal meningitis in Africa

MALSAT compiles images incorporating indices of rainfall, surface temperature, and vegetation, and relates these to the environmental factors associated with the timing and location of disease outbreaks. Current studies are adapting indices for identifying areas vulnerable to epidemics of malaria, meningoccal meningitis, and visceral leishmaniasis.
The objective is to work with health officials in African countries to develop early warning systems to identify areas where ecological conditions suggest risk of crop failure or disease. This approach requires access to computers for these health officials, availability of user-friendly GIS programs, and in-country collection of data by local meteorological stations. Regarding the results, MALSAT work has been tested in a number of sites in Africa showing that environmental variables such as rainfall estimates and vegetation indices can be provided by meteorological satellites (in this case METEOSAT and NOAA-AVHRR respectively were used) and correlated with malaria transmission indices.

Program needs addressed by MALSAT:

- Risk monitoring
- Targeted preventative measures

6.4.7 MEDical SATellite (MEDSAT)

NASA initiated the Biospheric Monitoring and Disease Prediction Project (BMDP) in 1985 in order to determine if remote sensing could be used to identify and monitor environmental factors influencing the spread of malaria. This effort included several research and feasibility studies. Initial studies monitored the development of canopy cover in California rice fields, using high-resolution images from LANDSAT-TM. The seasonal changes in the canopy cover have been successfully exploited to predict mosquito densities in the fields.

The BMDP also led to a study by NASA Ames and Lewis Research centers and the University of Michigan determining the feasibility of designing a low-cost satellite system called MEDSAT. The MEDSAT project would involve a remote sensing medical satellite helping in the control of vector-borne diseases, such as malaria. The system would combine visual/radar data and in-situ data to determine temporal and spatial variations of malaria risks. The information received from MEDSAT should enable public health resources to focus on the most vulnerable areas at the appropriate time. The state of Chiapas, Mexico, has been chosen as a good site to test the MEDSAT concept, because of high malaria risk and a good public health program that could benefit from the system.

This study concluded in the feasibility of such a light-satellite design, using a low-cost Pegasus launch (about US $8 million). Not only is frequent coverage possible for Chiapas, but it could be also easily applied to other tropical sites. A first order cost estimate to develop, construct, launch and operate MEDSAT, including five research sites for five years would be around $100 million over 12 years (cost established in 1992).

Program needs addressed by the proposed MEDSAT:

- Risk monitoring
- Targeted preventative measures
- More efficient management of resources required for treatment

6.5 The HI-STAR Strategy

The HI-STAR strategy consists of a two-phase approach, broken into a series of clear steps and key points to be addressed. It should be kept in mind that throughout the implementation process, the MIS and its dissemination system shall be monitored and their effectiveness evaluated after each phase/sub-phase.

The 2 phases required to ensure the success of HI-STAR are described as follows:

Phase I: The Development and Qualification Phase

Pre-Development

The development/qualification phase will require some initial funding to prepare a proper business plan in order to convince a target space agency to undertake the development of MIS within the framework of an existing program. Therefore this pre-development sub-phase will address the following steps:

- Presentation of the concept to foundations to obtain seed funding
- Preparation of a business plan
- Presentation of the business plan to space agencies
- Space agencies involvement in the Development and Qualification Phase.

Development and qualification

This phase, under the responsibility of space agencies, would consist of the development and qualification of MIS, working in close collaboration with the WHO as the end user or customer. The steps to be taken to develop MIS include:

- Combine current GIS data with advanced eco-epidemiological models
- Select one or two regions for pilot projects to verify the accuracy of outputs produced through this process
- Obtain feedback from WHO experts on usefulness of data produced
- Fine-tune system to ensure transferability to other regions

Phase II: The Operational Phase

Promotion

The promotion of the HI-STAR project must also be undertaken at this stage, in an effort to obtain additional funding and convince national governments in affected regions to use the MIS system.

The promotion sub-phase will therefore address the following issues:

- Update to business plan
- Promotion campaigns towards international organizations and governments

Operation

The goal of the operational phase is to ensure that targeted countries can in fact receive, generate and disseminate information and ensure continuity of the system. We therefore suggest that RBM - WHO operate the system with technical support from space agencies.

The goals of Phase II will include:

- Verify targeted country capability to access satellite data
- Ensure personnel are trained on the ground to input/gather eco-epidemiological data
- Ensure appropriate infrastructure to disseminate data
- Establish processing centers through existing space/health related facilities rather than create new centers, thereby minimizing overall costs of implementing the system.

Research and development activities will be required during both phases to have reliable and effective monitoring and prediction of malaria. In order to minimize these activities, it is proposed to combine existing programs or at least to take advantage of their best elements, while bringing innovative approaches identified in chapters 3, 4 and 5, such as advanced sensors and micro-satellites when possible. Numerous programs using space technology aiming to combat malaria have been studied in section 6.3. Key components of MIS have been identified within these programs at various stages of their development. The HI-STAR strategy therefore proposes to integrate MIS and a dissemination system by using already existing programs to take advantage of their expertise and resources and involving major actors, as identified in Appendix H.2.

Based on the overview of programs provided in sections 6.1 – 6.3, some existing technical programs have been identified. MARA could provide an appropriate framework as it already addresses the whole of Africa. The collection of ground data is crucial as inputs for MIS but also to calibrate and validate remote sensing database models. EMERCASE could provide an interesting approach for data collection and could be improved both in terms of costs and performance with the solutions presented in chapter 3. Advanced eco-epidemiological models selected from existing programs such as CHAART could be combined with current GIS data to produce the initial version of MIS. More generally, the technology to generate maps developed within the CHAART or MALSAT programs might offer the best accuracy, both in terms of location and prediction of malaria. Moreover, the concepts of the SatelLife program and its HealthNet network, combined with innovative methods proposed in Chapter 5 could provide a very efficient dissemination system for MIS. In case MIS would need to use new satellites, MEDSAT has already conducted a feasibility phase for low-cost remote sensing spacecrafts in 1992 (section 6.3). This concept should be compared with the more recent studies of micro-satellites referred to in chapter 3 in order to identify the best alternative.

Although clear technical key points have been identified, success of the HI-STAR strategy will depend on its ability to address a number of management, legal, promotion, funding and educational issues that will inevitably appear during the two phases. Suggestions to counter these challenges are presented in the next section.

6.6 HI-STAR Implementation Recommendations

Both in its development and operational phase, HI-STAR will have to address various issues to ensure a successful and effective implementation of the strategy. The following section provides implementation recommendations tailored to each phase.

6.6.1 Phase 1: Development and Qualification Phase

6.6.1.1 Organizational Structure, Legal and Political aspects

The structure proposed to manage the Development and Qualification Phase of MIS is a collaborative structure involving a policy-level health organization such as WHO and organizations with technical space-related expertise, namely one or several space agencies. NASA and CNES have already been carrying research programs for the use of space technology in vector-borne disease, such as in the case of NASA's CHAART program, and could contribute technical expertise to this phase. In creating such a structure, careful attention must be paid to the issue of intellectual property rights in raw data and processed images. For example, MIS may have to sign agreements that restrict the distribution of data in particular situations.

6.6.1.2 Technical Issues

Part of the HI-STAR strategy is that the technical expertise required during the Development and Qualification Phase of MIS shall be provided by space agencies. Since most national space agencies as well as international ones like ESA have experience using remote sensing technology, they appear to be a good incubator for MIS.

From data acquisition to delivery to the end-user, MIS has different time constraints depending on its use. When utilized as an early warning system, risk maps have to be generated by MIS and distributed to the stakeholders at least one month in advance, so that the susceptible areas, which are often not prepared for a malaria epidemic, can be provided in time with prevention and treatment means. The nature of the key data has a direct impact of how much advance warning time MIS can provide before the advent of an outbreak. For example, seasonal climate forecasts can provide warning of 6-10 months in advance, while changes in vector density can provide warnings only 2-4 weeks in advance.[34] Therefore, anti-malaria programs can be alerted of a potential outbreak between 2 weeks and six months prior to its occurrence.

When MIS is utilized as a monitoring system, the time constraint is different, as no prediction model needs to be applied. In that case, accuracy becomes a priority, as smaller variations of the data need to be detected. Assessment maps have to be available continuously and as quick as possible (in the order of one day lead time) so that teams in the field can act in real-time.

Data acquisition, data processing and analysis, data dissemination, user feedback and updating and maintenance of the system should be iterated at regular time intervals depending on time constraints.

6.6.1.3 Promotion and Funding

Health organizations might be hesitant to invest in a "space system", especially since its efficiency and effectiveness in combating malaria might not be widely proven. On the other hand, space agencies may be interested in proving that a system using space technology and data can be useful for global health issues. Thus, a pilot project in various countries could be funded by one or several space agencies together with international aid organizations. A private-public partnership to fund Phase-I implementation could provide an interesting alternative. This could be achieved by approaching information technology companies seeking to demonstrate the utility of their technology in exchange for the possibility of winning future contracts from NGO's or other programs. This approach appears to be endorsed by ESA's Data User Programme (DUP), a program whose goal is to help European companies develop and demonstrate information products from ESA missions.[35] Therefore, it is submitted that MIS may be an appropriate platform for demonstrating technology that may bring eventual commercial applications. A third possibility is to invite multinational corporations with subsidiaries or major interests in developing countries plagued with malaria problems to contribute to a project under the auspices of a space agency. In exchange for good publicity worldwide, tax incentives and a potentially healthier workforce in host countries, multinationals may be able to provide the initial funding required to finance the development of MIS. An overview of the activities to be undertaken in this phase, along with potential organizations to approach for funding are presented in table 6.1 below.

Table 6.1 - Financing scheme (Development/Qualification phase)

Phase	Sub-phase	Main activity	Funding
Development/ Qualification	Pre-development	Set-up a business plan Identify main requirements of MIS system (collaboration with WHO) Set up a base infrastructure Obtain seed-money	Foundations
	Development and qualification	Manage development of MISI Qualify and debug the system Perform demonstrations	Space Agency Public/Private Initiative or Multinational

As we can note from Table 6.1 the Development and Qualification Phase will require some initial funding in order to prepare a proper business plan. This plan will be important in convincing a target space agency (or multiple space agencies) or multinational to undertake the development of MIS in the frame of an existing program and obtain financial support. It may be assumed that this conceptual activity will require 6-12 months, with part-time staff to prepare and defend a business plan. The funds or "seed money" needed to finance this preparatory phase (estimate 150,000 USD) could likely be obtained from a foundation having public health as a vocation. Examples of such organizations are included in Appendix H.3, as for example the Bill and Melinda Gates Foundation or the National Health Library.

After securing the initial seed money, a HI-STAR marketing campaign is required. The promotion of any of the funding strategies mentioned above requires a campaign focusing on convincing decision makers, the health community and industry about potential benefits gained from the use of space technology to combat vector borne diseases. This can be done at a variety of health, information technology, aerospace and health-related conferences or workshops, which can be used to disseminate information concerning the utility of MIS. Some candidates for promotional activities include the United Nations' Committee on Peaceful Uses of Outer Space (COPUOS), the International Astronautical Federation (IAF) and malaria or vector-borne disease conferences. Effective promotions among a wide network of actors will

likely lead to synergies with other programs, such as Roll Back Malaria and MIM. Once again, effective promotion is the key to procuring resources to fund MIS.

Central aspects of promotions should vary according to the intended audience. For instance, an informational campaign directed at health specialists should concentrate on space programs like CHAART and EMERCASE, which have been effectively employed to fight vector-borne diseases.

On the other hand, promotional activities directed at politicians should focus on some economic benefits associates with space technology and MIS seen in Chapter 4. Some of these benefits include the more efficient distribution of limited resources required for malaria prevention and treatment, the development of technical expertise in developing countries, potential spin-offs and macroeconomic benefits associated with an effective anti-malaria program.

6.6.1.4 Education and Training

To increase awareness and build capacity on the use of MIS in affected countries, education needs to be provided. Participating countries could identify students to participate in education programs, with the intent of creating local system experts in the regions affected. The students should commit to follow through with the operational phase of the system and contribute to the operation of the system. To minimize the overall cost associated with this training, use should be made of existing centers in developed countries or UN Education Centers. There currently are 5 of these centers, which are located in India, Morocco, Nigeria, Brazil and Mexico. These centers aim to educate and transfer knowledge from space faring nations to developing nations, focusing mainly on space applications that are of benefit to the participating countries. Through making use of UN Education Centers, WHO Regional offices and other space or health related organizations already in existence in the affected countries, national students and doctors having participated in the education efforts of the development and qualification phase will participate in training others, increasing awareness at end user level, and convincing decision makers to ensure continued political and financial support.

6.6.2 Phase 2: Operational Phase

6.6.2.1 Organizational Structure, Legal and Political Aspects

It is recommended that the Operational Phase of HI-STAR be administered by RBM-WHO, although continue to receive technical support from space agencies. RBM-WHO was selected because it is an international organization with access to an existing medical infrastructure and malaria network. As a result, the organization would be an ideal relay to implement MIS and gather information for the MIS database. To ensure the successful implementation and the evolution of MIS, WHO member states and NGOs should also be offered participation in the program. NGO inclusion would likely be useful when national infrastructures are deficient or inexistent, or when a country is experiencing political instability. In effect, they could ensure continuity of the system when governments are unable to perform their health- related activities.

Partners might be asked to provide certain MIS inputs in exchange for accessing this global service. They could enter into international agreements or sign a "code of conduct" in which they commit to:

- Gather ground based data to feed MIS models
- Supply human, material or financial resources
- Contribute funds in accordance with their economic situation

Another example that could govern the relationship between the different partners could be that used by the European Global Monitoring for Environment and Security (GMES). GMES is a joint initiative of the European Commission and the European Space Agency (ESA) and has been designed to ensure continuous access to high-quality information services on the environment and security issues.[36] In GMES, the Commission is responsible for the policy aspects and ESA for the technical implementation. Although this collaborative framework is still under development, the success of GMES will depend largely upon a close cooperation between the two institutions. Using GMES as an example, it is possible that different partners could join in the development/qualification and operation of HI-STAR.

6.6.2.2 Technical Issues

The number and location of MIS databases are important because they must meet a number of requirements concerning backup, accessibility to the data, maintenance, and communications, also allowing for quick activation of prevention measures in response to the warnings. If decentralized, cost factors may limit the number of databases and lead to the choice of a host country with substantial infrastructure. This option must be weighed against the possibility of local database in developing countries, which offer a higher level of independence. To avoid difficult decisions concerning the number and location of databases, one solution could be a distributed database system that offers more flexibility and reliability in case of a failure of any of the components. Using such an Internet philosophy, the system would be more robust in that any user could take advantage of the whole system without having the possibility to block information flow. The hardware technology to host these database segments would be more affordable for developing countries and housing a local segment would give developing countries the feeling of owning a tangible part of MIS. In the case of lack of telecommunications infrastructure, satellite telephones and very small aperture terminal (VSAT) networks could provide enough bandwidth to operate the system.

6.6.2.3 Promotion and Funding

Once the initial pilot projects successfully demonstrate their efficiency, it may be assumed that an updated business plan will be required, similar to the development/qualification phase, to promote the HI-STAR strategy to international organizations in order for them to

adopt the program at a larger scale. The idea is to have RBM-WHO, as the health authority and political organization join forces with the space agencies.

A period of 6-12 months needs to be calculated to take into account inclusion in budgetary cycles of these organizations (assuming they have been involved in the demonstrations of the previous phase). Funding of this effort, in the order of another US $150,000 could come from a foundation, from the IT industry interested in the operational phase design or from a large industrial group looking for a good "corporate image".

Funding for continued operation and maintenance of the MIS and its dissemination system will require on-going financial support. Such funding could be provided through collaboration between various international health and aid organizations, NGOs, federal agencies and potentially through the national Health Ministries of the countries benefiting from the system. Again, a list of potential funding organizations is included in Appendix H.3.

Table 6.2 - Financing Scheme (Operational Phase)

Phase	Sub-phase	Main activity	Funding
Operational	Promotion	Update the business plan Promotion campaign towards international organizations	Foundation/ Industry
	Operational	Coordination with space agency Integration of other entities Establish center network Start operations	International Organizations

In terms of operations, the system will likely require funding from a variety of sources. If MIS follows traditional anti-malaria programs, funding may be provided through a partnership of major international organizations, including:

- Organizations concerned with global health issues such as the WHO, the World Bank or the Global Fund, UNDP, UNICEF, USAID
- Development banks such as the European Bank for Development and Reconstruction, the African Bank for Development, the Asian Bank for Development
- Various foundations such as the Bill and Melinda Gates Foundation, the National Library of Medicine, OXFAM
- Regional organizations, states, and other sources such as private partnerships with companies providing satellite data, software or hardware

Also, it is possible that HI-STAR can receive partial funding from some of the major international programs and initiatives discussed above in section 6.1.

In the Operational Phase, HI-STAR would possibly have to procure remote sensing data from various sources. There are at least three potential options for reducing data acquisition and processing costs associated with MIS in the operational stage. The first involves the space agencies of space-faring nations, which are usually able to obtain data at a reduced cost for scientific research and humanitarian initiatives. Examples of this are the European Space Agency's ENVISAT and the Canadian Space Agency's RADARSAT. Therefore steps can be taken to explore the availability of data and willingness of such agencies to contribute to the MIS effort. A second option is to promote synergy between on-going programs using the same data, such as the Famine Early Warning System (FEWS). A third strategy is to embark upon a partnership with private sector: Commercial satellite companies may be willing to invest in such an initiative if they are able to generate potential returns, such as free advertising, tax incentives or the promotion of their satellite technology.

If particular satellite companies are not interested in donating their images, there is also the possibility that images can be obtained at a discounted rate. However, even at discounted prices, the lack of resources in affected countries may reduce their ability to access imagery, train personnel and acquire image processing equipment. It is important to highlight that initiatives like MALSAT, which conduct training programs and distribute post-processing software free of charge provide a potential model for reducing the costs of MIS. Also, there is the possibility on entering into a private-public partnership, as demonstrated by the Disaster Monitoring Constellation (DMC) seen in Appendix G. The DMC project demonstrates that commercial satellite companies may be willing to invest in particular initiatives if they have government support and if they see a potential return on investment.

6.6.2.4 Education and Training

To ensure the operation of MIS, education must be provided that can be divided within two categories:

i) Training for collection and communication of data

MIS users should know how to interpret and acquire data and how to feed MIS databases with parameters (eco-epidemiological data) collected on the ground. Users/regional officers should be able to interpret the MIS product received to ensure proper reaction to the warning bulletins. Coupling education with local research on MIS improvement would also be very useful.

ii) Training for processing/distribution/interpretation of data

A certain level of technical training is required for the processing, distributing and interpreting data. Through making use of UN Education Centers, WHO Regional offices and other space or health related organizations already in existence in the affected countries, national students/doctors having participated in the development/qualification phase and education effort will participate to this effort.

To implement this system, special departments in charge of MIS could be established within the United Nations Education Centers or other space or health-related facilities. The training staff would be provided by the different actors of MIS as part of their contribution to the system. Non-governmental organizations being part of the program should train their specialists and provide researchers and lecturers for MIS departments, just as governmental healthcare organizations.

Training on how to collect and send reliable ground base data has to be specifically addressed. MIS Departments should therefore provide training material adapted to the locals conditions. They have to define procedures and tools to disseminate information in accordance with local configuration.

6.7 Conclusion

The strategy proposed in this section attempted to cover all aspects required to ensure a successful implementation of MIS and promote synergy between space technology and health programs/initiatives to combat malaria. The strategy must always be mindful of the needs of the programs that it is attempting to help and the existing capability in the region affected. As proposed in section 6.5, the creation of MIS requires that the international anti-malaria programs listed in section 6.1 be consulted in order to determine how MIS can best build on current programs and be effectively disseminated. This requires a high level of coordination and cooperation with space organizations, as health organizations are more familiar with the realities and constraints on the ground, while space agencies and current programs making use of space technologies are knowledgeable of the technical constraints and limitations to be overcome. HI-STAR must also be highly attentive to user feedback, which can be used to improve the system.

An estimate of the planning requirements to complete the 2 phases is included below, with specific milestones for feedback and review. This estimate will need to be continually updated during the pre-development phase.

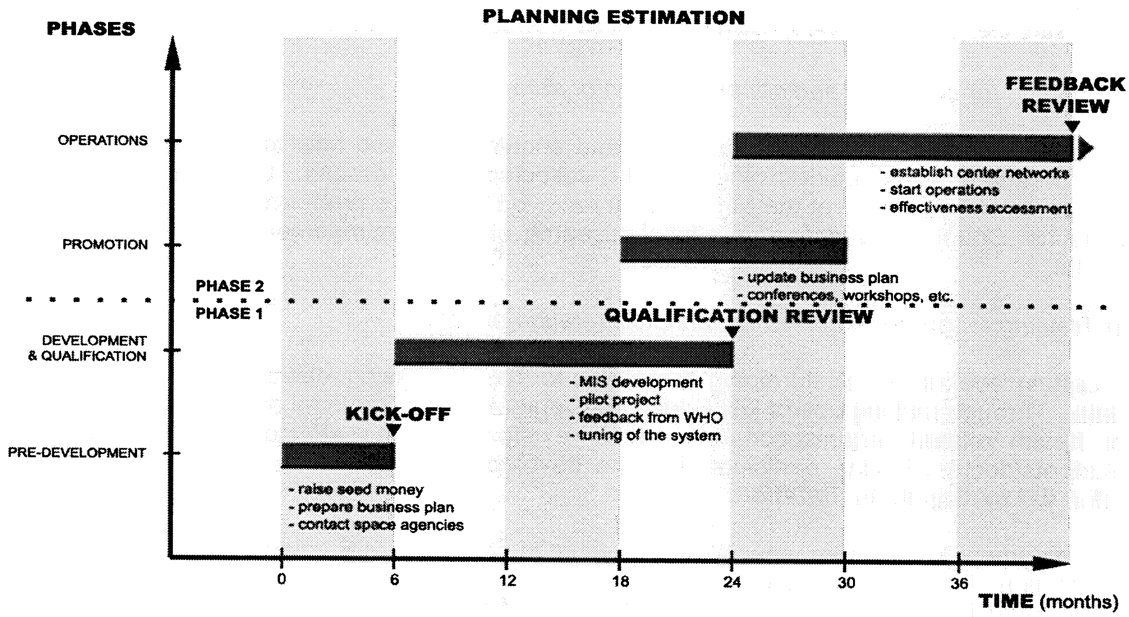

Figure 6.4 – Strategy Implementation Timeline, Milestones and Phases

The most effective way of ensuring program success is to provide a service that demonstrably helps in the battle against malaria. The following chapter will study four specific cases, demonstrating how HI-STAR and MIS in particular can help in the fight against malaria.

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7

Case Studies

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Chapter 7 - Case Studies

In order to promote the successful implementation of the MIS program, the HI-STAR team considered countries across the globe. The team assessed a number of factors based upon initial research to help determine which countries would be the most appropriate to pursue an in depth analysis.

Most important, the burden of malaria in a particular country was evaluated. With the major region affected by malaria related casualties in Africa, it was determined that this would be a suitable region of study. Africa suffers 90% of all the casualties induced by malaria (*based on WHO studies*).

Another factor assessed was the population at risk of malaria. In evaluating this risk, it was determined that the studies should focus on areas where a significant number of people would be affected by the research. The majority of the world's population lives in Asia and lives in conditions where the malaria risk is significant.

Research also indicated a direct link between poverty and malaria burden. Where funds are available for malaria risk mitigation, countries have achieved success in suppressing malaria. Political structure, geography, and existing space infrastructure and programs were also determining factors, as a thorough methodology was desired.

The initial research indicated that in Africa, Kenya and Nigeria would be good examples of regions for implementation. India and Indonesia were chosen as representatives from Asia. In the following sections more information will be outlined to help validate the selection of each of these countries.

The subsequent section will present the case of each country with its background and unique characteristics. In addition to factors limiting the malaria initiatives across the world, each of these countries has distinct issues. The focus of this chapter will be to show how the MIS program can be instituted in each country. Costs and economic benefits will be outlined as factors each country must consider when implementing the MIS program.

One of the major limiting factors in each country was a lack of accurate and up to date malaria risk maps. The dissemination of any information also presents a significant obstacle to these countries. Funding a program to adequately resolve these problems must also be addressed.

7.1 Kenya

The selection of Kenya for case study results directly from the magnitude of the malaria problems that exist within its borders. A basic overview of Kenya's political, economic, and technological standpoints is given, as well as an overview of the malaria programs that currently exist in Kenya. This information, melded with an introduction into the space technologies that are being utilized in this country, will be used to generate an action plan for improving the monitoring and control of malaria.

7.1.1 Background Information

Table 7.1 - Kenya Background Information[1]

Geography	
Total Area:	582,650 sq km
Location:	Eastern Africa, bordering the Indian Ocean, between Somalia and Tanzania
Climate:	varies from tropical along coast to arid in interior
Terrain:	low plains rise to central highlands bisected by Great Rift Valley; fertile plateau in west
People	
Population:	30,765,916 (July 2001 est.)
Population growth rate:	1.27% (2001 est.)
Infant mortality rate:	67.99 deaths/1,000 live births (2001 est.)
Life expectancy at birth:	47.49 years
Languages:	English (official), Kiswahili (official), numerous indigenous languages
Economy	
GDP - real growth rate:	0.4% (2000 est.)
GDP - per capita:	$1,500 (2000 est.)
GDP - composition by sector:	*agriculture:* 25% *industry:* 13%, *services:* 62% (1999 est.)
Population below poverty line:	42% (1992 est.)
Telecommunications	
Main lines in use:	290,000 (1998)
Telephone system assessment:	Unreliable; little attempt to modernize except for service to business
Satellite Earth Stations:	4 Intelsat
Internet users:	45,000 (1999)

Kenya has been a republic since gaining its independence in 1964. The current president is Daniel arap Moi, elected in 1978. Kenya faces a period of political and economic uncertainty as Moi is constitutionally required to step down at the next elections that must be held by early 2003.

The major infrastructural shortfalls in Kenya are felt in the power and water supply, telecommunications, roads and rail, and port facilities. Telephone service is generally unreliable. Kenya has moved in the direction of rural-based health services, concentrating more on the prevention of the mundane everyday diseases; such as dysentery, malaria, poor nutrition and sanitation which are the real causes of high morbidity and mortality.

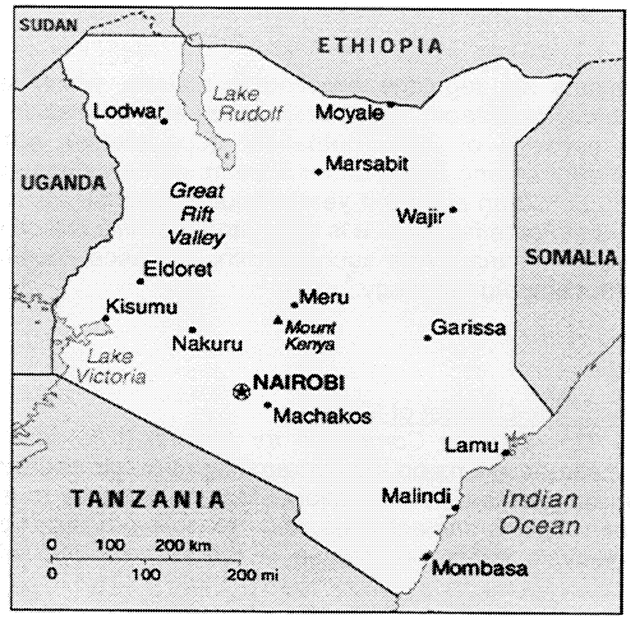

Figure 7.1 – Map of Kenya[1]

As a country, Kenya seeks a close relationship with foreign investors, particularly those from western countries. The result of heavy investment from abroad is a substantial reinvestment of earnings by private companies operating in Kenya. This has provided a major contribution to industrial expansion in the post-independence years. However, an overall improvement in the strategic management of the industrial sector is still required.

7.1.2 Malaria in Kenya

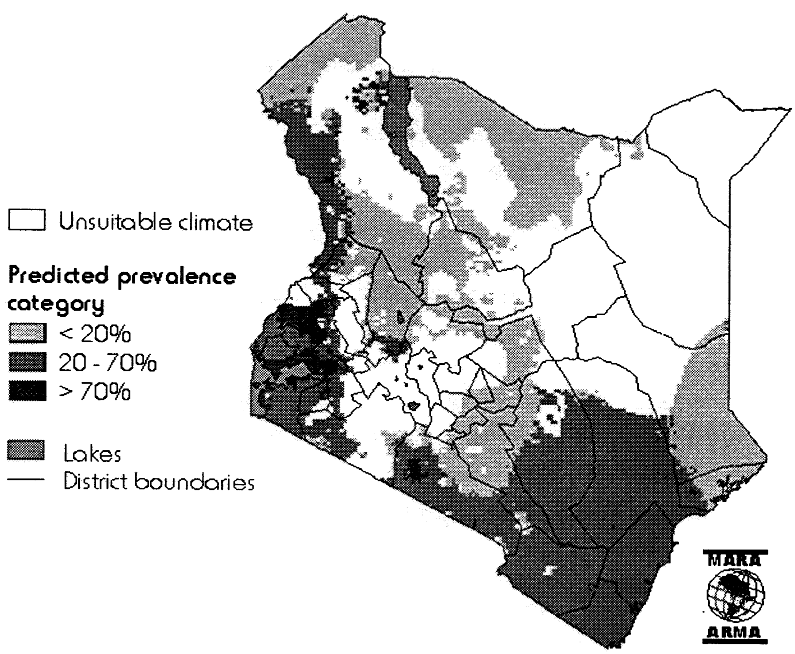

Figure 7.2 - Distribution of Malaria in Kenya[2]

7.1.2.1 Impact

Some 20 million Kenyans are regularly exposed to malaria, which remains the country's leading cause of morbidity and death. Clinic attendance and admission to hospitals shows a proportional malaria morbidity of 30% (outpatient departments), out of which 19% are admitted. Malaria mortality among those under 5 years old is estimated at 26,000 deaths a year while over 145,000 children aged 0-4 years require hospitalization. Malaria case fatality rate is around 6% in health care facilities. It is estimated that 170 million working days are lost annually in Kenya due to malaria.[3] With such alarming statistics, malaria is the number one target in Kenya's health campaign strategy.[4]

7.1.2.2 Initiatives

National Organizations in the Combat of Malaria
Kenya's *Inter-Agency Coordinating Committee for Malaria* (ICC) is a body constituted by *Ministry of Health* to make decisions on the overarching strategic and managerial issues. The ICC provides a forum for partners in the National Malaria Strategy to exchange information, coordinate malaria control plans and activities, and measure progress against objectives. The executive body for Kenya's policy on malaria is the responsibility of *Division of Malaria Control* (DOMC).

The Kenyan government is strongly committed to the combat of malaria, and spends US $10 million/year to fight malaria.[5] A National Malaria Strategy and a Malaria Information System are also defined in Kenya.

The Kenyan National Malaria Strategy (NMS) has four key strategic approaches to control malaria:

- Guaranteeing access to rapid and effective treatment (case management).
- Providing malaria prevention and treatment to pregnant women.
- Ensuring the use of insecticide treated nets in at-risk communities.
- Improving malaria epidemic preparedness and response.

Two supporting structures are identified to ensure effectiveness of strategic approaches.

- Information, education and communication (IEC).
- Monitoring, evaluation and research

The Kenyan Malaria Information System (KMIS)[6] is an initiative of the Ministry of Health and has been launched as a new coordinated effort to support malaria prevention and control across the country. The KMIS provides information on the following:

- Which partners are working on malaria in each district
- Which districts receive donor support for malaria-related activities
- Population estimates of the target groups within each district
- Details on malaria risks, malaria vectors, anti-malarial drug resistance
- Allied nationally derived malaria reports, guidelines and strategic plans

KMIS has been used as a vehicle to capture available sources of information necessary for national and district-level decision-makers and is aimed to be updated every 6 months.

7.1.2.3 International Organizations and Programs in the Combat of Malaria

Kenya relies on the support of a number of international organizations and programs to combat malaria. These programs include Roll Back Malaria (RBM), Multilateral Initiative on Malaria (MIM), Mapping Malaria Risk in Africa (MARA), and the East African Network for Monitoring Anti-malarial Treatment Efficacy (EANMAT).

RBM has developed and implemented guidelines on epidemic preparedness and response. RBM has also trained health personnel in epidemic prone districts. The drug policy has been reviewed and SP had been adopted as first line drug. Activities to implement the new anti-malaria drug are in process. Ongoing activities are taking place in the strategy development on communications and of ITN and other inventions. Kenyan government has expressed a high level political commitment to the RBM program.[7] The required budget for a 5 year period is foreseen at US$84.5 million.[4]

MARA/ARMA have collaborated to provide an atlas of malaria for Africa, containing relevant information for rational and targeted implementation of malaria control. MARA has set up a functional network of scientists / institutions within Kenya. It is training people in the use of GIS, other databases, and in predicting climate change.[8]

EANMAT is an initiative of Ministries of Health and National Malaria Control Programs and National Research Institutions in Kenya, Uganda, Tanzania, DFID-East Africa, and Well-come Trust. The project aims to strengthen the regional information base on parasite chemo sensitivity on which rational treatment policy and effective chemotherapy for malaria can be based. The network has high-level commitment and support within Ministries of Health in the three countries. The joint sub-regional initiative brings together not only the three national malaria control programs but also other operational and research expertise, as part of a network. The network should provide dynamic assessment of the situation through comparable national and regional data for improving malaria therapies that are urgently needed for control of malaria in the region. Information on the efficacy of anti-malarial treatment will be obtained using technology appropriate to the problem and the skills and resources of the region.[9]

7.1.2.4 International and National Health Organizations and Programs

International and national health organizations and programs also participate in the mitigation of malaria risk in Kenya. These organizations include: United Nations International Children's Emergency Fund (UNICEF), Merlin, Kenyan Red Cross (KRCS), and the African Medical and Research Foundation (AMREF). An outline of Kenyan specific programs is provided below. Merlin is a young and fast developing charity that keeps costs to a minimum and is working in the most difficult spots around the world in extra difficult circumstances. Merlin is working with local health authorities, training local doctors and nurses, aiming to make the projects sustainable from the start. In Kenya, Merlin combated a local epidemic in the years 1999-2000.[10]

The KRCS is officially recognized by the government as a voluntary relief society, auxiliary to the public authorities, and particularly to the medical services of the armed forces. For over a decade, the KRCS has been responding to a series of emergencies resulting from both natural and man-made disasters, among others seasonal outbreaks of disease in particularly cholera and malaria.[11]

AMREF is an independent non-profit, non-governmental organization whose mission is to empower the disadvantaged people in Africa in order to improve their health conditions. AMREF has three core strategies to achieve its mission: capacity building, operation research, and advocacy. AMREF's approach places emphasis on developing, testing and evaluating methodologies and systems that are appropriate, relevant, affordable and effective. AMREF has a set of defined, priority intervention areas among which are malaria.

The AMREF Africa programs depend on funds raised mostly from Europe and North America.[12]

7.1.3 Space Infrastructure

7.1.3.1 Kenya's Space Related Regional Centers

Space technology is primarily used in Kenya for surveying, mapping, and meteorology. Two space related regional centers can be found in Kenya. The Regional Center for Mapping of Resources for Development, sponsored by the UN's Economic Commission for Africa (RCMRD), is one center, and the other is the Regional Meteorological Training Center (RMTC) within the World Meteorological Organization (WMO) Training Network of Centers.

RCMRD programs include resource mapping, remote sensing and environmental management, human resources development, and engineering services. This center uses satellite data from LANDSAT MSS, LANDSAT TM, NOAA, METEOSAT, and SPOT images for the Eastern and Southern Africa sub-region. The center's operating costs are contributed largely by the contracting member states, as well as funding from a number of donors. The key donors include, USAID, UNDP, FAO, EU, World Bank, IDRC, UNESCO, BADEA, and bilateral donors such as France, India, Italy, and the Netherlands.[13] The center also generates some of its own funding from consulting, training, and technical services.

RMTC consists of a network of 24 stations that is linked to world meteorological centers in Washington, Moscow, and Melbourne. It is connected to the Meteorological Data District System through METOSAT. This center is sponsored by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT).

Kenya is also home to ESA's Malindi Ground Station. This S-band facility contains uplink and downlink equipment, a ranging system, timing and calibration equipment, a station computer, and a station/ESOC communications system. Malindi can also be used for L-band and X-band operations.

7.1.3.2 Kenya's Space Related Environmental Programs

Satellite data has also been used in many environmental programs across Africa. The UN's Food and Agriculture Organization (FAO) began the Africover Project in 1997.[14] Their goal is to establish a digital geo-referenced database on land cover and a geographic referential for Africa at a 1:200,000 scale. Africover products rely on remote sensing data and Geographic Information Systems (GIS) to prepare basic geographic information on natural resources in African countries and to reinforce the establishment, update, and operational use of the geographic referential, the land cover maps and the geo-databases. This project has been financed by the Italian government, which will have funded US $9.3 million from the time of the project's inception in 1997 until September 2002. Africover utilizes Landsat Thematic Mapper's 25 m spatial resolution data integrated with existing aerial photographs and aerial survey maps. Investigations are in progress to access the availability of other possible sensor data, such as from Russia's high-resolution imagery RESURS 01.

7.1.3.3 Kenya's Space Related Malaria Programs

For the purposes of this study, the interest lies in what programs are specifically investigating Kenya's malaria problem.

Early warnings for malaria would enable effective measures to be taken before a major outbreak. Some current research efforts using space technologies are exploring these studies in Kenya. One system able to give early warning is MALSAT, developed by a team of scientists from the Liverpool School of Tropical Medicine in the UK. The MALSAT research group has been developing and testing Environmental Information Systems (using Geographic Information Systems and weather satellites) for malaria control planning as part

of a DFID-funded research project (Department for International Development) in Namibia, Kenya and Zimbabwe.[15]

MALSAT accesses the utilization of Remote Sensing and GIS for direct use in malaria control planning. MALSAT also explores options for the development of Environmental Information Systems which can provide a crucial component to improving malaria control operations.

Another group of scientists, led by the Canada Centre for Remote Sensing, has studied the use of Canada's RADARSAT-1 for monitoring malaria risk in Kenya.[16] Using Kenyan coverage data from 1999-2001, the research presented the concept for Synthetic Aperture Radar to help identify areas of high mosquito abundance. Land cover classes were categorized and wetland areas in particular were clearly identified. Results correlating wetland areas and high mosquito abundance were significant. The proposed forward research included analyzing land cover classifications from the RADARSAT-1 data using a GIS in order to identify those high mosquito risk areas which are in close proximity to populated areas. RADARSAT-2 will be launched in 2003, adding more robustness and capability to satellite coverage being studied for Kenya's malaria issues.

7.1.4 Implementation and Cost Analysis of MIS

A national space program does not exist in Kenya. However, several programs use satellite data to benefit a variety of Kenya's problems, whether environmental or health related. Kenya has the facilities to handle the remote sensing data and the infrastructure to disseminate the information using GIS systems. Although Kenya has satellite image processing facilities, the country needs international assistance for the actual data and funding of programs and facilities.

Providing the Kenyan government with MIS will directly enable it to improve malaria prevention and case management. The Kenyan government spends US $10 million per year on fighting malaria. The MIS tool would allow the Kenyan government to use its public resources more effectively and efficiently. Nevertheless, Kenya has limited ability to pay for the MIS. It will require outside funding in order to enable the Kenyan government to stand stronger in the battle against malaria.

Figure 7.3 shows a possible way for implementing MIS in Kenya through existing organizations. The data processing for the provision of the malaria risk map can be performed within Kenya. An organization identified to be highly suitable to generate the malaria risk maps is Africover. Africover makes use of remote sensing data and the Geographic Information Systems to generate geographic information on natural resources in African Countries. At the moment, the provision of malaria risk maps is not within the scope of the organization, however knowledge on and equipment for data processing is available. In order to enable Africover to provide the risk maps, Africover needs to have access to the satellite data. International assistance will be required for this satellite data.

This work could be performed within the MARA/ARMA functional network to supplement its efforts of providing an atlas of malaria for Africa. Both organizations Africover and MARA/ARMA work with national institutions and organizations. The malaria risk map is provided to the Division of Malaria Control of the Ministry of Health, which implements the information in the existing Kenya Malaria Information System, coordinates the use of the tool and makes sure that the health organizations have access to the information.

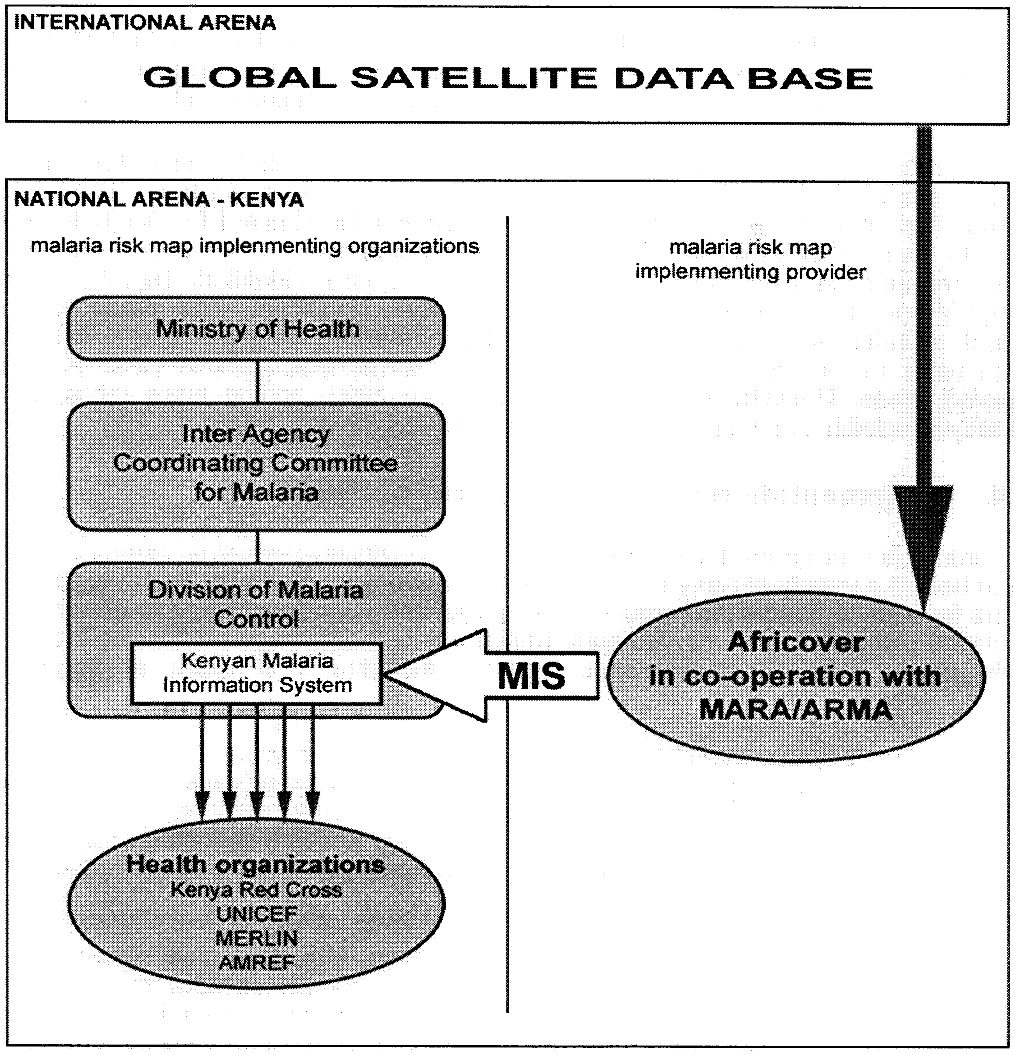

Figure 7.3 - MIS Implementation Strategy for Kenya

Estimations on the investment cost to set-up the MIS-system in Kenya and the subsequent operation costs, based on analysis in Chapter 4, are given in Appendix E. An overview of these cost assumptions is given below:

7.1.4.1 Built-up costs

Two regional centers already exist and can share their resources to carry out the MIS program. In order to cover all areas of the country, two additional ground stations could be built. With a population of 30.7 million, it would be useful to have at least 300 dissemination points. The initial investment cost is approximated at US $2.3 million.

7.1.4.2 Operation Costs

The active centers in Kenya can share the downlink cost of the data. The dissemination costs are high, so it should be important to minimize these costs. The estimated yearly operational cost is US $0.7 million for Kenya. In case of a pilot project these costs can be omitted. This leaves approximately US $600,000 for operating the system.

With these investment and annual costs, Kenya will require international assistance, both in initial funding and in receiving satellite data. After the initial start of the MIS implementation, it is assumed that Kenya will handle the costs of the program itself. Early prevention of malaria can generate a variety of benefits, from health enhancement to a growth in tourism. These benefits can ultimately save Kenya money that can be allocated to the MIS program.

7.2 Nigeria

Nigeria's position in Africa is worthy of note because it has the largest population in Africa (one out of every 4 Africans is a Nigerian) and plays a major role in the Organization of African Unity (OAU) as well as Economic Community of West African states (ECOWAS). There is a huge malaria burden in Nigeria (the disease is endemic in 90% of the population spread).

7.2.1 Background Information

Table 7.2 - Nigeria Background Information[17]

Geography	
Total Area:	923,768 sq km
Location:	Western Africa, bordering the Gulf of Guinea, between Benin and Cameroon
Climate:	varies; equatorial in south, tropical in center, arid in north
Terrain:	southern lowlands merge into central hills and plateaus; mountains in southeast, plains in north
People	
Population:	126,635,626 (July 2001 est.)
Population growth rate:	2.61% (2001 est.)
Infant mortality rate:	73.34 deaths/1,000 live births (2001 est.)
Life expectancy at birth:	51.07 years
Languages:	English (official), Hausa, Yoruba, Igbo (Ibo), Fulani
Economy	
GDP - real growth rate:	3.5% (2000 est.)
GDP - per capita:	$950 (2000 est.)
GDP - composition by sector:	*agriculture:* 40% *industry:* 40%, *services:* 20% (1999 est.)
Population below poverty line:	45% (2000 est.)
Telecommunications	
Main lines in use:	500,000 (2000)
Telephone system assessment:	An inadequate system, further limited by poor maintenance; major expansion is required and a start has been made
Satellite Earth Stations:	3 Intelsat (1 Atlantic Ocean and 1 Indian Ocean)
Internet users:	100,000 (2000)

Nigeria has a population of 126 million (based on 2001 figures). Nigeria is the third fastest growing country behind only India and Pakistan. This high population density affects the economic and social situation in Nigeria. Estimates in 2000 indicate that over 45% of the population lives in poverty conditions. This is significant, as the WHO has found that there is a direct correlation between health and wealth. The poverty conditions also contribute to a stagnant 57.1% literacy rate.[17]

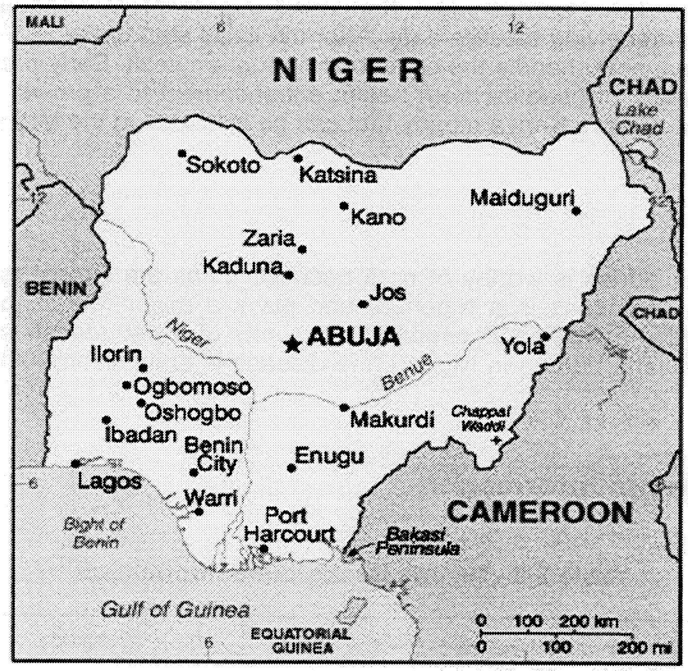

Figure 7.4 – Map of Nigeria[18]

Nigeria's workforce of 66 million contributes to produce a GDP of US $117 billion (based on 2001 estimates).[17] Nigeria is also burdened with a number of other health care issues, including AIDS and Tuberculosis. These additional issues subtract from the overall available health care budget. These factors limit the amount available for malaria programs.

Nigeria, located on the west coast of Africa, plays a major role in the politics and power of Africa. Gaining its independence in 1960, Nigeria has gone through a succession of leadership reformations. Currently the government is operated as a stable democratic republic. A limiting factor to Nigeria's development is the lack of adequate telecommunication infrastructure. This constrains information dissemination and education of the general population and presents a significant obstacle in mitigating the malaria risk in Nigeria.

7.2.2 Malaria in Nigeria

7.2.2.1 Impact

Malaria is endemic throughout the country. It poses a significant threat as three species of the parasite exist including strains which exhibit resistance to common treatments. Over 90% of the population lives in areas where a stable malaria risk is present. According to RBM statistics malaria significantly influences the high morbidity and mortality with a prevalence of 919/100000 especially among children and pregnant women. Malaria is estimated to be responsible for 25% of infant mortality and 30% of childhood mortality, accounting for one third of hospital admissions and doctor visits. Failure rates for the common treatment with chloroquine are relatively low, yet increasing across the country.[18]

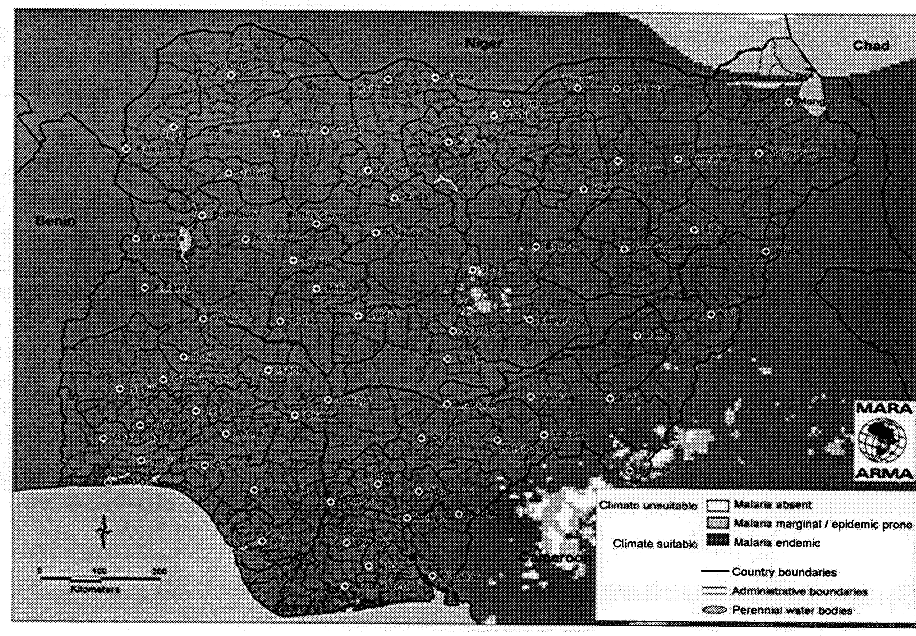

Figure 7.5 – Distribution of Malaria in Nigeria[3]

7.2.2.2 Initiatives

Nigeria relies heavily on internationally based malaria programs mainly backed by WHO, the World Bank, Medecins Sans Frontieres (MSF), and USAID. The main ongoing malaria programs include Roll Back Malaria, The Harvard Malaria Initiative, MIM and MARA.

Nigeria's association with RBM began in its early stages. In 1998, Nigeria was a test bed for validating the effectiveness of situation analysis instruments. It is now in the process of implementing these instruments into existing health care infrastructure. Training health care workers how to handle severe malaria cases has been a high priority. These workers are also trained to promote and educate people about bednets and other preventive measures. These education policies have extended to community leaders and women's groups to promote the use of malaria preventive measures. Nigeria is dedicated to the RBM initiative and actively participates in RBM conferences.[23]

The Harvard School of Public Health founded the Harvard Malaria Initiative in order to discover, develop, and test drugs that will defeat drug-resistant malaria. Based on basic scientific research into malaria multidrug resistance, conceptual pathways to effective drugs will be mapped and significant findings will be used for practicable prevention and treatment strategies. The Initiative is seeking US $10 million in support from outside sources.[19]

MSF has been a participant in the malaria risk mitigation in Nigeria. Teamed with local communities and health care workers in the Nigerian state of Bayelsa, MSF participates in a survey of regional malaria outbreaks. A concurrent study has determined that misdiagnosis by the malaria patients has been a problem in early treatment. Education is a prime goal of this organization and health care workers are trained in diagnosing and treating malaria.[20]

Along with these international programs, Nigeria is actively involved in national and regional based programs.

AMPAC is a community based non-governmental organization dedicated to fighting malaria in Nigeria. The initiative focuses on massive community health education on the causes, prevention and control of malaria. Community malaria committees (CMCs) are formed to carry out basic intervention like home management of malaria, treatment and re-treatment of nets, community health education, *etc.* These committees sustain the activities of AMPAC in the communities by giving seminars on malaria control in schools and national and state level

seminars/workshops. Community projects enable them to ascertain baseline malaria situation in such communities - such as treatment and prevention practices available and perception and attitudes to bednets. Research into traditional remedies available in such communities is also carried out.[21]

The Center for Health Sciences, Training Research and Development (CHESTRAD International) promotes a program called INT-Oraide. CHESTRAD is a non-profit, Nigerian NGO designed to assist health care institutions. This assistance includes participating in efforts to reduce the burden of tropical diseases such as malaria. ITN-Oriade, a CHESTRAD program, was set up in 1999 to reduce the mortality and morbidity due to malaria. The program is being used in four states of Nigeria. Education is a major emphasis for the ITN-Oraide program. The education extends beyond teaching people to use insecticides and insecticide treated materials to increasing the affectivity and reach of the referral systems and data management systems. ITN-Oriade is aimed at the community level and seeks to take existing facilities and increase the operability and capacity to combat malaria. Funding for this program has been secured partially by the B zone of UNICEF. The implementation of the program is set up such that communities will take charge of the initiatives proposed.[22]

7.2.3 Space Infrastructure

The National Space Research and Development Agency (NASRDA)[23], created by the Nigerian government, will spend US$93m in the development of a space program. The NASRDA has indicated that it is interested in applications that will assist Africans in the alleviation of poverty, in food security, the inventorying and sustainable management of Africa's natural resources and improvement in telecommunications. Satellite data are useful for solving these problems. The space program will also benefit health, basic education, and economic stability.

NASRDA is to have six centers, including the National Center for Remote Sensing (NCRS). For the near term, the plan is to develop the permanent site of the NCRS in Jos as well as to build a national Earth observation ground receiving station. For the longer term, intense training and education will be utilized towards Nigeria building its own Earth observation and communication satellites by the year 2003. Currently there are no plans to implement this remote sensing technology for mapping malaria. By using space technology, it is possible to augment and improve existing malaria initiatives.

Ongoing studies have shown that using space technology has been successful when used in the application of remote sensing and geographic information systems in the prevention of disease outbreaks in Nigeria. An example of such a study is the RS/GIS for prevention of water-borne diseases in Nigeria under the aegis of TWF/CHAART program, to be utilized for rational location of water supply facilities in different regions of the country. The RS images of the area will be used to map land cover, vegetation, hydrology and towns. The GIS database will also include spatial and quantitative information on disease patterns, population data, transportation infrastructure, and existing clean water facilities. Computer modeling will enable determination of the impact of population changes and seasonal fluctuations. The experience gained in this study could be used on a regional scale to guide funding agencies to implement water development schemes.[24]

Nigeria's space infrastructure consists of mainly telecommunication ground stations. These stations could play an important role in the dissemination of malaria information throughout the country.

7.2.4 Implementation and Cost Analysis of MIS

Based on the findings of the studies of malaria programs in Nigeria, an oft-cited inadequacy is that of a malaria risk map. Malaria risk mapping is only one of many factors that could contribute to the mitigation of malaria risk in Nigeria. Education of the population and health care officials is still the prime factor in relieving the malaria risk in Nigeria; however, the addition of the MIS program could help in this regard. Smaller programs in Nigeria have exhibited openness to new information and possibilities for the dissemination of malarial information throughout the country down to the local and regional level. Cooperation with local programs and national health ministries will significantly increase the effectiveness of information dissemination.

A major step in the implementation of MIS is to show that it will be cost effective for Nigeria. Costs and benefits can be found in a number of ways. By alleviating the malaria problem costs of treatment will be decreased. Money spent on treatment applies not only to the purchase of expensive medicines, but also to travel and facility expenses.

The focus of this initiative is to effectively use data gathered for prevention and possible control of communicable and non – communicable diseases through information exchange among the Health workers in the country. However it is imperative to note that the data is useful only if it is accurate (*i.e.* gathered with as much precision as possible) and subsequently disseminated through the appropriate means to reach the end users/target audience as fast as possible with considerable coverage. From information gathered on the problems facing malaria programs primarily gathered from the WHO, the table below indicates the benefits of using MIS.

Table 7.3 - Benefits Using MIS

Item	Problem Description	Benefit of using MIS
1	Traditional data gathering techniques and Community health methods have proved to be very ineffective in cataloging the patterns of diseases and vectors in Nigeria.	The accuracy/precision of the data gathered using MIS is very high given the diversity of the data gathered through ground based and satellite data components of the system.
2	In most developing countries there is a dearth of health workers most especially in the Public/Community health sectors. This is due mainly to the limited number of trained personnel, *i.e.* Doctors, Nurses, and Community health staff. This condition has impacted much on the spread of personnel over large expanses of land	There is no limit to the horizon of the earth observation satellites employed for remote sensing in the MIS. Thus, large expanses of land can be covered in the country where personnel may be lacking. The critical mass of the personnel needed for the MIS will be concentrated on data entry, interpretation and processing as well as dissemination via telecommunication systems, all of which will complements the existing community health structures

Item	Problem Description	Benefit of using MIS
3	Public /Community health programs are characterized by lack of intra and inter-sectoral collaboration. This leads to verticalization of programs and multiplicity of disease reporting formats, thus compromising efficiency and quality of data	MIS will have a holistic and centralized management that will ensure effective coordination amongst all the various levels involved and will interface smoothly with all the tiers of government (*i.e.* Federal, State, and Local) to ensure effective implementation.
4	Lack of basic infrastructure (*e.g.* communication equipment, transport and data management tools); and dearth of skilled manpower for case detection, data collection analysis and interpretation are some problems identified, which militate against effective disease surveillance in existing programs.	MIS is a hybrid system of satellite technology as well as ground based technologies; the use of satellite technology overcomes the limitation of terrestrial obstacles for effective communication and information dissemination as well as limits the need to travel long distances for information exchange. Data analysis and interpretation are centralized to centers where there exists skilled manpower.
5	Non-existence of functional public health laboratories in most states of the federation and deficient capacity at all levels to forecast and respond in a timely and appropriate manner to epidemics and disasters were also blamed for inaccurate ascertainment of cases and poor response to epidemics and disasters.	Risk Maps are developed in the MIS and made available to end-users across the federation in a timely fashion to militate against the outbreak of epidemics and also inform of any kinds of endemic diseases.

Thus, it becomes imperative to evolve new techniques that will provide accurate and informative data of the factors that affect public health. MIS offers this cost effective new technique.

7.2.4.1 Initial and Operational Costs of MIS

Based on the cost approach from Chapter 4, a rough order of magnitude initial investment estimate of approximately US $3.9 million is required to set up a MIS in Nigeria. These estimates are based on the existing space infrastructure in Nigeria. Nigeria's existing ground stations could be used for data reception and as hubs for information transfer to larger databases. Operating costs in Nigeria would be about US $1.4 million per year. Dissemination of information across Nigeria is responsible for the majority of the cost. Detailed cost information can be found in Appendix E.

These high costs, coupled with the country's meager funding capabilities, may restrict Nigeria from implementing MIS. International assistance will be required for the successful implementation of MIS. These costs should become less restrictive as Nigeria successfully uses MIS to combat malaria, easing the burden or diagnosis and treatment expenditures. Nigeria should also experience an increase in the GDP. This will increase available funds to support health care initiatives, including MIS.

7.3 India

India has been selected for study because of its importance in the South Asia region, and because it accounts for a sixth of the world's population. In addition, India struggles to deal with both endemic and epidemic malaria. It also has a significant space program, including remote sensing and telecom systems.

7.3.1 Basic Information

The republic of India originated in 1947 from nonviolent resistance to British colonialism under Mohandas Gandhi and Jawaharlal Nehru. The former British colonial empire was divided into the secular state of India and the smaller Muslim state of Pakistan. A third war between the two countries in 1971 resulted in East Pakistan becoming the separate nation of Bangladesh.

Table 7.4 - India Facts[25]

Geography	
Total Area:	3,287,590 sq km
Location:	Southern Asia, between Burma and Pakistan
Climate:	Varied: from tropical monsoon in south to temperate in north
Terrain:	upland plain (Deccan Plateau) in south, flat to rolling plain along the Ganges, deserts in west, Himalayas in north. Lowest point: Indian Ocean, highest point: Kanchenjunga 8,598 m
People	
Population:	1,029,991,145 (July 2001 est.) mostly in rural areas
Population growth rate:	1.55% (2001 est.)
Infant mortality rate:	63.19 deaths/1,000 live births (2001 est.)
Life expectancy at birth:	62.86 years with low difference between male and female
Languages:	Official language: Hindi, spoken by 1/3 of the population. More than a dozen "official" languages in India.
Economy	
GDP - real growth rate:	6% (2000 est.)
GDP - per capita:	$2,200, 6% real growth rate (2000 est.)
GDP - composition by sector:	*agriculture:* 25% (but majority of the labor force) *industry:* 24%, *services:* 51% (2000)
Population below poverty line:	35% (1994 est.)
Telecommunications	
Main lines in use:	27.7 million (October 2000)
Telephone system general assessment:	Telephone density at about two for each 100 persons, waiting list of over 2 million.
Satellite Earth Stations:	8 Intelsat and 1 Inmarsat
Internet users:	4.5 million (2000), one person out of 300.
Access to television broad casting:	90% of the population
Fundamental concerns	
There exists an ongoing dispute with Pakistan over Kashmir, massive overpopulation, environmental degradation, extensive poverty, and ethnic strife - all this despite impressive gains in economic investment and output.	

Figure 7.6 - Population Density in India

Analysis of relevant maps shows that malaria is widespread over most of the country. The malaria burden is particularly high in the northern parts, just south of the Himalayas, an area where per capita income is the lowest and population density is the highest. India has a requirement to improve education on basic notions related to health and disease prevention. Due to the lack of satisfactory telecommunications infrastructure in the near future, alternative methods to disseminate information should be considered. Finally, cost effectiveness of malaria prevention on a national scale should be promoted to ensure government budgetary support.

7.3.2 Malaria in India

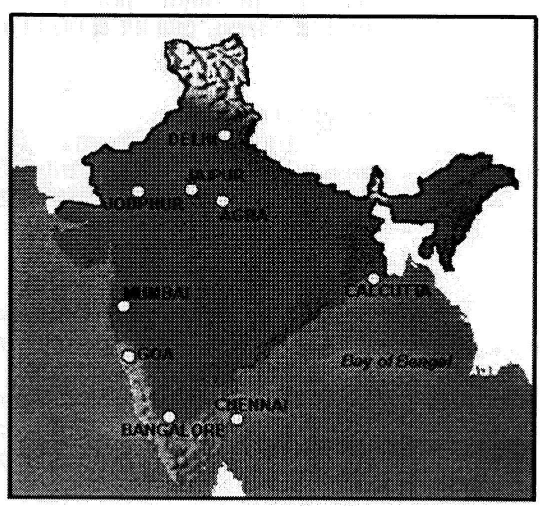

Figure 7.7 – Distribution of Malaria in India[26]

7.3.2.1 Impact

The risk of malaria is prevalent throughout the year across the entire country except in regions that are above altitudes of 2000 m. Nearly 2-3 million cases of malaria occur each year in India, resulting in approximately 1000 deaths[27]. The estimated economic loss due to malaria in India from 1990-1993 is US $506.82 million to US $630.82 million.[28]

In India, approximately 40% of malaria infections are caused by *Plasmodium falciparum*[29], described in Chapter 2. In highly endemic areas, individuals may become infected with one or more species of the malarial parasite resulting in 4-8% of malaria cases with mixed infection. There are seven primary malaria vectors, which differ greatly in their biological characteristics, geographic distribution and breeding habitats[30]. Since 1997 the Indian government spends nearly 50% of its health budget fighting malaria[31] amounting to US $40 million in 1997. 70-80% of the malaria control money in India is spent on insecticides.[32]

Although the number of cases of malaria in India had significantly declined during the 1960's, malaria has re-emerged as a major health concern in India due to increasing parasite resistance to drugs, vector resistance to insecticides, and increasing population migration. *P. falciparum* resistance to chloroquine was first reported in the Diphu area of the Karbianglong district in Assam in 1973[33]. Later studies have shown that the incidence and distribution of drug-resistant *P. falciparum* is increasing. The actual incidence of drug resistant malaria in India is difficult to determine because many cases may not be recorded. There is evidence demonstrating the presence of vector resistance in India to DDT and malathion. India's malaria programs suffer from insufficient resources, lack of inter-regional collaboration and shortage of trained professional staff. To complicate matters, extensive rural development activities result in population migration, which could precipitate malaria epidemics as susceptible individuals move into malaria-infested areas.

7.3.2.2 Initiatives

Activities relating to controlling malaria are integrated within the general health services in India[37], whilst the Director of Malaria Control Programs (MCP) is responsible for overall malaria control activities. Two malaria programs are currently active in India: The National Anti-Malaria Program (NAMP)[34] and Roll Back Malaria (RBM). These programs have been successful in reducing the malaria burden from 6.5 million in 1976 to 3 million in 1997. These programs are now joining their efforts to improve the response to the malaria problem.

The NAMP, implemented in 1979 is based on a National-Regional 50:50 cost-sharing basis, except for the poorest North-Eastern States, where malaria is endemic, here the cost is covered nationally. The NAMP uses a number of insecticides[35], including DDT, Malathion, Pyrethroid and Deltamethrin. DDT is a domestically manufactured low cost insecticide. Malathion and the Pyrethroid however are reported to cost three times as much as DDT and this presents NAMP with significant budgetary concerns when trying to extend the conventional insecticide spraying programs, especially in the face of a huge and expanding population.

The Indian Council of Medical Research, is investigating a number of new technologies[36] including Geographic Information Systems (GIS) for use in mapping the distribution of *Anopheles dirus* in India. There also exist ongoing research activities stemming from the Integrated Vector Control Project, which are developing new anti-malarial drugs, diagnostic kits, insecticides and repellents for epidemic investigations and bioenvironmental methods for malaria control.

External financial assistance to aid in combating the disease includes funds from the Global Fund to Fight AIDS, Tuberculosis and Malaria[37]. They allocated US $4.5 million on April 25, 2002 to Southeast Asian countries. The Indian government also borrows money from the World Bank to better combat malaria. One such example is the loan that the government has contracted in early 1997[38]. The objective is to create an enhanced and more effective malaria control program that uses malaria control interventions such as integrated early detection and treatment, is responsive to local needs through more selective and appropriate use of insecticides and personal protection measures, strengthens the National Malaria Eradication Program (NMEP) by improving epidemic planning and rapid response and modifies its orientation. In the long-term, the enhanced malaria control program will reduce death, morbidity and social and economic losses from malaria. The total cost of the proposed project is under discussion. Tentative estimates are between US $200 to US $210 million. The World

Bank, acting through International Development Association (IDA) would finance about 85 percent of the project cost, approximately US $164 million.

On November 19th, 1999, India's Malaria Research Center in cooperation with state health authorities, initiated a program that utilized India's IRS-1C and IRS-1D remote sensing satellites to identify and monitor malaria-carrying mosquito breeding sites. Satellite imaging was integrated with commercially available GIS software to forecast malaria outbreaks and to direct mosquito control activities by locating breeding sites and estimating the number of mosquitoes arising from these sites. Thematic digitized maps on altitude, temperature, soil type and rainfall conditions were utilized to construct maps that indicated areas of favorable ecological conditions that support the breeding of the six primary malaria vectors found in India. In addition, an educational course module on utilizing GIS surveillance systems was developed in order to train four health officers from district and state headquarters[39].

Prior to the project's inception, a number of validation studies on using remote sensing for malaria control have been performed to test its effectiveness. By November 1999, the researchers had mapped the distribution of two malaria vector species throughout the whole of India. The project's future goals were to map the distribution of the other four primary malaria vectors throughout India. Once the distribution of each vector was ascertained, then this data would be combined with satellite information on water bodies, human habitation, vegetation and surface contours in order to predict potential malaria epidemics and to implement malaria prevention measures.

The project was limited by two factors: cloud cover and satellite spatial resolution. Cloud cover interfered with the availability of useful satellite imagery. The spatial resolution available in 1999 was 6 m, which prevented the identification of small water bodies - sites of high mosquito breeding activity. However, the problem of spatial resolution is expected to be resolved with the future launch of a 2.5m resolution capability Indian satellite.

7.3.3 Space Infrastructure

India is one of few nations capable of building and launching a spacecraft. It has developed substantial resources and facilities to provide space capabilities and technologies. Furthermore, there is a political will in India to keep developing space access and related technologies as shown by the budget of Department of Science and Technology that was raised by 52 % in 2001[40]. India's space activities will be decisive in any MIS implementation.

7.3.3.1 Ground Stations

There are many Satellite Earth Stations on the Indian Territory that can be used to collect data. Ownership of these facilities is between three entities:

1) The Department of Telecommunications (DOT), shown in Figure 7.8
2) Software Technology Parks of India (STPI)
3) Videsh Sanchar Nigam Limited (VSNL)

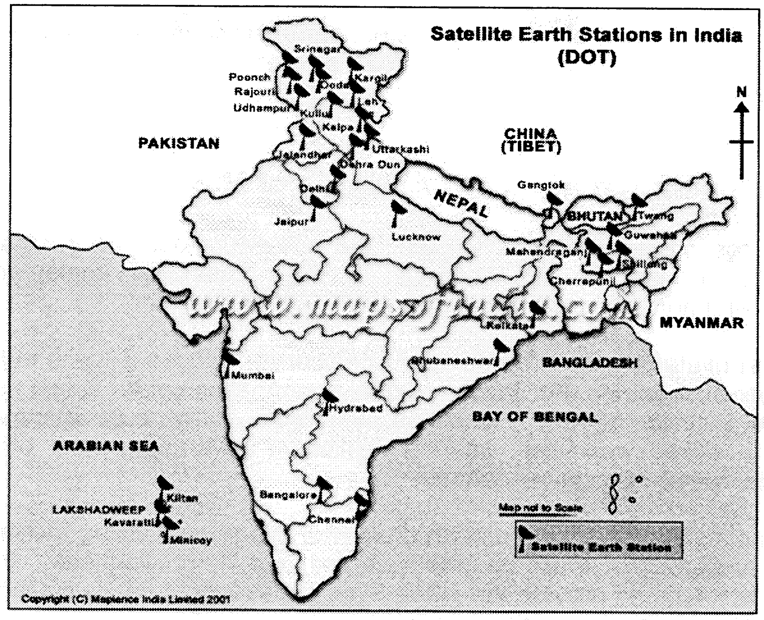

Figure 7.8 - DOT Ground Stations in India[41]

Indian Space Research Organization (ISRO)

The Indian Space Agency operates two satellite networks, Indian National Satellites System (INSAT) and the Indian Remote Sensing Satellites System (IRS). INSAT was established in 1983 and is exploited by a joint venture of the Department of Space (DoS), the Department of Telecommunications, the India Meteorological Department, All India Radio and Doordarshan (Indian Television).

IRS was commissioned with the launch of IRS-1A in March 1988. The IRS System is under the responsibility of the National Natural Resources Management System (NNRMS) which currently operates five satellites: IRS-1B, -1C, -1D, -P3, -P4 launched successively from August 1991 through March 1999.

These satellites provide India with a sophisticated remote sensing capability and data for the monitoring and management of natural resources and environment. IRS-P5 and IRS-P6, which are planned at for launch at the end of 2003, will further enhance Indian capabilities and are intended for agriculture applications.

National Remote Sensing Agency (NRSA)

Figure 7.9 - Remote Sensing in India

NRSA possesses its own ground station at Shadnagar. It is dedicated to data reception and tracking, archival and real time data retrieval. The data reception activity started using the Landsat satellite in 1979. Nowadays, NRSA has a multi-mission capability: it can receive and process data from most of the current remote sensing satellites (INDIA'S IRS SERIES, USA'S LANDSAT-5, NOAA-14 & 15 AND EUROPEAN ERS-1 & 2) and is capable of producing 25000 images per year[42].

Up to now, the main interest of NRSA resides in natural resources management: agriculture, forestry, geology, land cover, ocean, soil, urban studies and water resources. Vector-borne disease environmental monitoring is currently not a point of focus.

7.3.4 Implementation and Cost Analysis of MIS

Initial systems costing for India has followed the procedure outlined in Chapter 4. A cost breakdown table is included in Appendix E. The estimated implementation cost is US $14 million, and annual cost is estimated at US $5.4 million.

Much of the cost of starting up MIS could be significantly reduced if it was to be implemented across a number of countries. For India, a global coordination center would need to be linked NRSA and NAMP. India already possesses substantial software development capabilities, hardware and a skilled workforce, offering significant advantages over other countries in establishing and operating regional centers.

Where India has significant space infrastructure and image processing facilities in place, the cost for image procurement would be drastically reduced, if not eliminated. India also has its own satellites, which could provide the information necessary to input into the MIS database. Using these existing systems would minimize operational costs.

In 1997, US $40 million was spent for fighting malaria. As 70-80% of the malaria control money in India is spent on insecticides, increased efficiency of treatments will clearly bring substantial cost savings. A 10% reduction in insecticide use would offer a saving comparable to the MIS operation costs.

It is concluded that MIS implementation costs could be covered within the budget of ISRO, which was US $470 million in 2002[43]. Operational costs may then be accommodated by NAMP, and as has been may be offset by the saving in insecticide expenditure.

The benefits of employing the MIS program would be much the same as those of other developing nations. As the overall health of a country is directly linked with its output, it is advantageous for India to participate in any program, which would minimize the effects of malaria.

7.4 Indonesia

The world's fourth most populous country and largest archipelago, Indonesia is a vast polyglot country. Independence was gained from the Netherlands in 1949, and Indonesia is currently a republic, in transition to full democracy following four decades of authoritarian rule. Its strategic location along major shipping lines, and its status as the world's largest producer of liquefied natural gas position Indonesia as an influential state in the South East Asia (SEA) region, and in the world economy[44]. The country possesses significant space infrastructure, but does not involve it in its current anti-malaria programs.

7.4.1 General Information

Table 7.5 - Indonesian Facts[45]

Geography	
Total Area:	1,919,440 sq km
Location:	Southeastern Asia, equatorial archipelago of 17000 islands between Indian Ocean and the Pacific Ocean
Climate:	tropical; hot, humid; more moderate in highlands
Terrain:	mostly coastal lowlands; larger islands have interior mountains
People	
Population:	228,437,870 (July 2001 est.)
Population growth rate:	1.6% (2001 est.)
Infant mortality rate:	40.91 deaths/1,000 live births (2001 est.)
Life expectancy at birth:	68.27 years
Languages:	Bahasa Indonesia (official, modified form of Malay), English, Dutch, local dialects, the most widely spoken of which is Javanese.
Economy	
GDP - real growth rate:	4.8% (2000 est.)
GDP - per capita:	$2,900 (2000 est.)
GDP - composition by sector:	*agriculture:* 21% *industry:* 35%, *services:* 4% (1999 est.)
Population below poverty line:	20% (1998)
Telecommunications	
Main lines in use:	5,588,310 (1998)
Telephone system assessment:	Domestic service fair, international service good. Inter-island microwave system and HF radio police network; domestic satellite communications system
Satellite Earth Stations:	2 Intelsat (1 Indian Ocean and 1 Pacific Ocean)
Internet users:	400,000 (2000)
Fundamental concerns	
Implementing IMF-mandated reforms of the banking sector, effecting a transition to a popularly elected government, and resolving growing separatist pressures in Aceh and West Papua [Irian Jaya].	

It is necessary to review recent economic and political events in order to appreciate the current national issues and priorities that Indonesia faces. Indonesia's economy collapsed spectacularly during the East Asian crisis of 1997-98. Real GDP fell by 20% in 18 months and at one point the country's currency, the rupiah, had lost over 85% of its value against the dollar[46]. But the economy's collapse brought political rebirth, and the authoritarian regime was replaced by a fledgling democracy. There has since followed two reformist governments, whose priorities have been concerned with economic recovery, reform of the military and

legal systems, and resolution to the secessionist troubles in the outer, resource rich provinces of Aceh and West Papua [formerly Irian Jaya] shown in dark below.

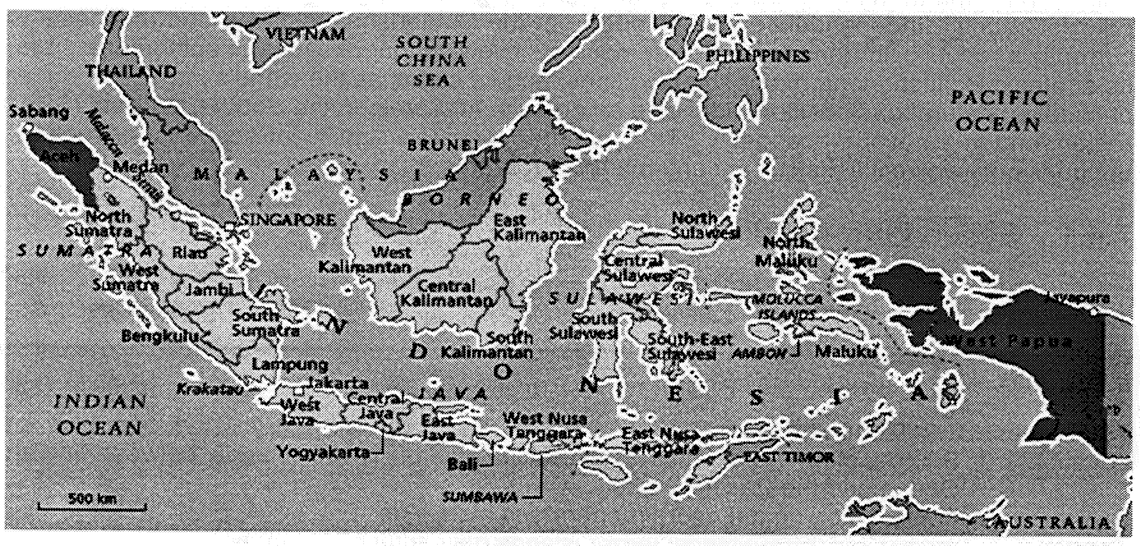

Figure 7.10 - Map of Indonesia [46]

The greatest concentration of economic, military and political power resides on the island of Java, whose population totals 100 million. While Malaria has long been endemic in the outer provinces, their status as conflict regions has led to low investment in and low priority for health services. The outer provinces also suffer from low literacy rates, poor transport and communications infrastructure and language barriers. Many of the world's most culturally isolated communities can be found in West Papua, which until as recently as 1974 practiced cannibalism. In contrast, Java has long been an economic hub for the greater SEA area and has for the last 30 years managed to control much of its malaria burden. Recently, and for a number of reasons including the economic crisis, malaria has begun to spread again to the populated centers of Java, and is threatening a number of major cities previously free of the disease[47].

7.4.2 Malaria in Indonesia

7.4.2.1 Impact

Over the past five years, malaria has become a major infectious disease in Indonesia with an official 3.5 million malaria cases reported annually. An overall analysis by the WHO estimates for 2000 a total of six million malaria cases, including 700 deaths due to malaria[48]. Currently 70 million people are living in ecologically risky areas with eastern outer islands particularly affected. However, also in Java and Bali, two of the most populous islands in Indonesia, 39 out of 117 districts are categorized malaria endemic areas. The following are the main reasons for this malaria outbreak:

- Major landscape change due to fishpond and sand extraction for construction resulting in mosquito breeding site increase;
- Building and mining operations with limited environmental impact assessment;
- Population movement due to an increase in seasonal worker demand;
- Increased anti-malarial drug resistance.

The economic crisis of the past four years has also adversely affected the national malaria control program. Smaller national and local budgets for malaria control activities have severely reduced outreach initiatives. The situation has had an immediate impact on vector

control programs in rural areas, especially outside Java and Bali. In addition to the lack of laboratory facility technicians, people living outside Java and Bali have also found their access to public health facilities hampered.

7.4.2.2 Initiatives

Despite the economic crisis, several sectors within the central government are providing a strong commitment to support Indonesia's malaria control program. Among others, the Ministry of Agriculture has generated a legal base regarding regulations on irrigation and planting schedules, which have proven critical to vector management success in central Java while the Ministry of Tourism has become involved in information dissemination with regard to malaria risk in main tourist destination. At the sub-national level, local governments have been involved in malaria programs in terms of inter-sector co-ordination of the development of transmigration settlement areas. For instance the University of Gajah Mada in Yogyakarta has established the National Training Center for Malaria and other Vector-Borne Diseases and the University of Sam Ratulangie in Manado has conducted training on malaria case management[49]. At the grass-roots level, local communities have been actively involved in early detection and prompt, simple malaria treatment. They organize and conduct activities through 240,000 integrated health posts and village drug posts.

Non-governmental organizations such as World Vision Indonesia, WATCH, the European Community Humanitarian Organization, Medecins Sans Frontières and Merlin are all actively involved in assisting local governments to educate communities to help in the burden of fighting malaria.

In an effort to coordinate and integrate the above high and low level initiatives, Indonesia has started to actively implement the WHO Roll Back Malaria (RBM) inception action via its Gebrak Malaria program. Started as a local plan limited to three endemic locations for two years, it has recently been expanded to cover the national territory. This community movement aims to increase malaria program coverage and quality according to local specific needs. The program's official target is to reduce malaria incidence to less than 1 per 1,000 population in Java, Bali, surrounding islands, industrial sites, and tourist areas by the year 2010. Mortality in 2010 should have decreased by 75% compared with situation in the year 2000. It is important to notice that to achieve this ambitious objective, Gebrak Malaria implementation strategy explicitly mentions the use of GIS: "*Maximize the gains by use of available technology to address the problems in the countries of the region. The technical resource networks will be utilized for early diagnosis and prompt treatment, through mainstreaming of the control efforts and through surveillance including the use of GIS*"[50].

Indonesia is also a member nation of the ACTMalaria initiative that comprises Bangladesh, Cambodia, China, Lao PDR, Malaysia, Myanmar, Philippines, Thailand, and Vietnam. This international effort, established in 1996, has as an underlying principle the equal and collaborative participation between associated countries. The mission of ACTMalaria can be summarized as capacity building and improved communication. To achieve its objectives, ACTMalaria has established the following implementation strategy:

- Training: courses developed by a Technical Core Group and Curriculum Committees. The Technical Core Group is a permanent advisory group consisting of one member from each of the partner countries. The Curriculum Committees are ad hoc groups formed by course organizers according to the needs of each particular course.

- Communication: each country has a designated contact person, and a web site www.actmalaria.org was established in 1997, which includes a data bank providing information on core training courses, training material, curricula and timetables.

ACTMalaria efforts are supported by a number of international organizations among which the European Commission's Regional Malaria Control Programme in Cambodia, Laos, and Vietnam (EC-RMCP) plays a major role.

7.4.3 Space Infrastructure

Indonesia's unique island geography presents a variety of communications, resource monitoring and infrastructure problems for which space activities are well suited. As a result, Indonesia developed a substantial space infrastructure early-on.

7.4.3.1 Space Organization and Programs

Indonesia possesses two space agencies whose mandate is to focus on the applications of existing space technologies, in line with the national development priorities. Their organization is shown in figure 7.11.

The national space coordination agency is the National Council for Aeronautics and Space of the Republic of Indonesia (DEPANRI), with the President of the Republic of Indonesia and the Minister of State for Research and Technology as Chairman and Vice-Chairman, respectively.

The National Institute of Aeronautics and Space (LAPAN) is the principal national Research and Development organization responsible for the implementation of the aerospace program in the country. LAPAN budget for the fiscal year 2001 was is Rp.21.2 billion earmarked for development, while the routine funding is Rp.16.4 billion (approximately US $2 million and US $1.6 million respectively).

Some large-scale projects implemented by Indonesia include the Land Resource Evaluation Program, Marine Resource Evaluation Program, Environmental Management Development in Indonesia, Coastal Environment Management Project, Coastal Zone Resource and Management Project, Application of Radar Data in Indonesia, Satellite Application Technology Transfer in Indonesia and National Forest Inventory. There is currently no focus on environmental monitoring for vector-borne disease control.

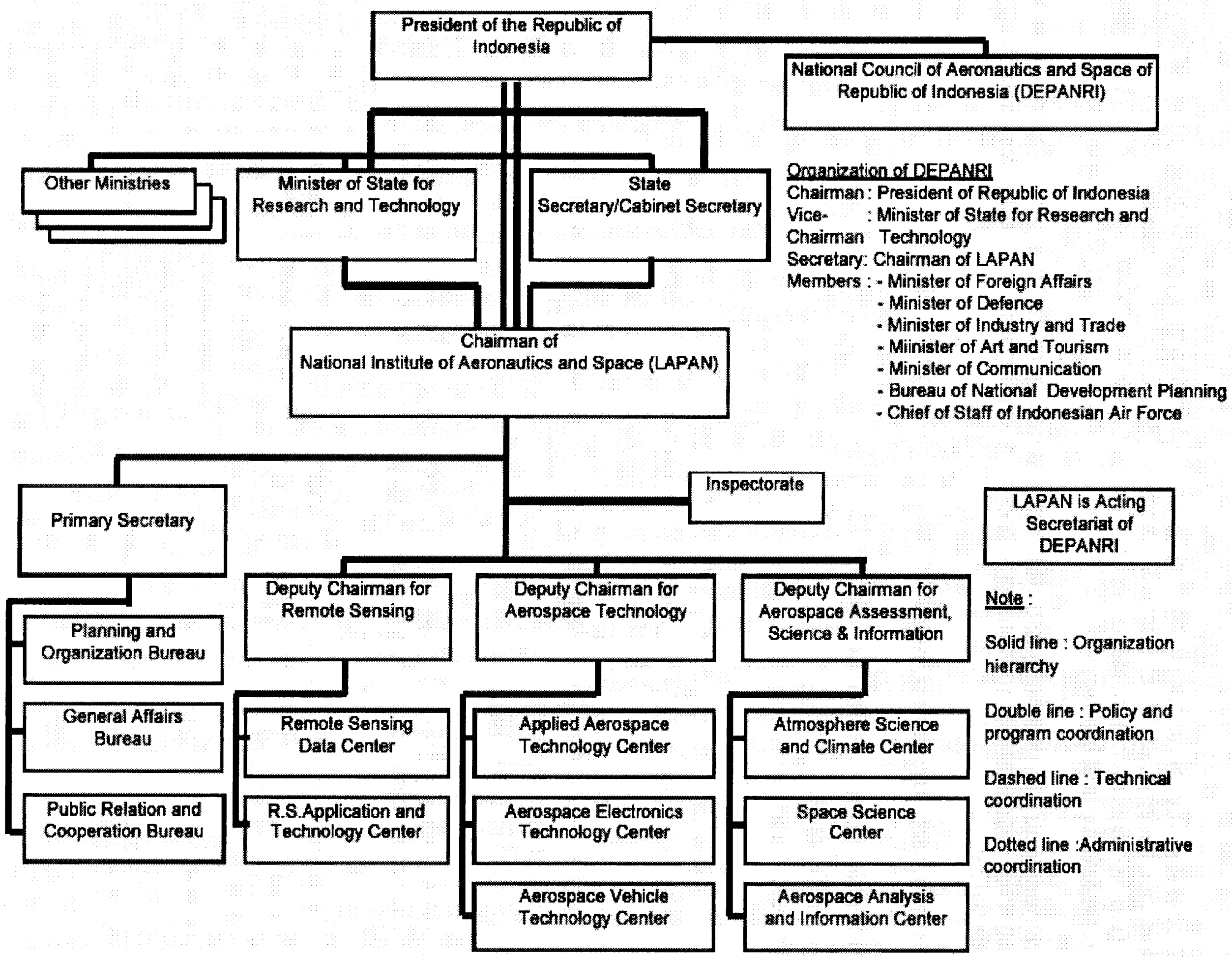

Figure 7.11 - Space Activities in Indonesia[51]

7.4.3.2 Space Infrastructure

Indonesia was the first developing country to have its own operational domestic satellite communication system; where the first Palapa satellite was launched in 1976[52]. Several commercial organizations, such as Datacom and PT Media CitraDatacom, provide direct broadcast television and radio services and communications networks specifically for Indonesia. Indonesian industry also hosts several other companies planning to develop cellular phone networks using communications satellites in partnership with other Asian countries.

Indonesia operates a ground receiving station for the acquisition and processing of data from various remote sensing satellites, such as Landsat, SPOT, ERS-1 and JERS-1. Indonesia is also engaged in the development of its own aeronautical navigation satellite surveillance system for the twenty-first century.

To support development planning and national resources monitoring, in 1969 the Indonesia government has established a National Coordination Agency for Surveys and Mapping (BAKOSURTANAL).

This organization provides a number of different services and products:

- Geodetic Surveys (GPS, Leveling, Gravity);
- Aerial Surveys;
- Remote Sensing;
- Database System Network;
- Geographic Information System (Development and Application);
- General Mapping (Topographic, Exclusive Economic Zone, National and Administrative Regional Boundaries, Sea Navigation, Aeronautical, Spatial Planning);
- Thematic Mapping (Various Natural and Environmental Themes with Land and Sea Coverage *e.g.*: Land Cover, Geomorphology, Drainage Pattern *etc.*);
- Education and Training;
- Research and Development;

BAKOSURTANAL has among its objectives to "develop a Geographic Information System for national, provincial, district and city level purpose in order to be synergic, efficient and effective"[53].

Currently, this agency is not directly involved in the generation of specific malaria risk maps within its GIS program. However, based on their experience and overall capabilities (in particular thematic mapping activities), BAKOSURTANAL could be capable of providing a specific malaria GIS service.

7.4.4 Implementation and Cost Analysis of MIS

Introduction of the proposed MIS strategy in Indonesia must take into account the specific aspects of this nation as described in this section. It can be seen that implementation of the MIS system would benefit from an approach that relies on the existing space infrastructure, GIS activities and malaria control programs. MIS in Indonesia could take full advantage of the local space technologies capabilities - in particular of remote sensing satellite image acquisition and processing, mapping and GIS related activities and existing malaria control network at national and local level.

Many studies that investigated the monitoring of malarial environments have developed models for producing adequate malaria risk maps, based on the predominant factors of interest to be monitored. However, as is naturally the case, the pilot project will begin with a very limited budget, and is often also confined geographically to a small area or island. As such, environmental factors have been measured on the ground by field workers, and GIS has been limited to aerial surveys. Clearly the geographic extension of these early studies, whereby the maps are to cover many islands and the number of sites increased dramatically, would benefit greatly from space based sensing and GIS. However, this stage of planning has often been beyond the scope of such studies, and much valuable dialogue between the malarial model builders and the space offices has not taken place. The first step of implementation therefore, is to promote such dialogue.

National offices useful for implementing this plan can include:

- The GIS-Health Space Office within LAPAN Remote Sensing Applications Department, responsible for acquisition, processing and distribution of satellite/aerial imagery and weather information;
- The GIS-Health Data Office within the Gebrak Malaria national agency, responsible or the collection, maintenance and distribution of malaria information collected on the ground at national, regional and local level;
- The GIS-Health Map Office within the BAKOSURTANAL Deputy for Base Mapping Department, responsible for development of a Malaria Information System based on a database integrating satellite/aerial imagery with the collected malaria information.

The next step would be the production, distribution and maintenance of the Indonesia Malaria Risk Map. This activity falls directly within the GIS-Health_Map office and again relies on a strong interrelationship with the Gebrak Malaria initiative for effective results distribution.

Further steps deal with the primary concern of education. Relying on the above interagency partnership Gebrak Malaria should promote the creation of a specific GIS-Heath training curriculum tailored to the needs of top health officials as well as volunteers acting at local community level.

In order to increase government support MIS implementation should start as a pilot project limited to affected regions of Java. This should be followed after a one to two-year trial period, by the gradual extension of the program to cover the national territory.

Finally, this initiative should be reported and promoted within the ACTMalaria consortia. In particular, GIS training programs could be conducted in the framework of the ACTMalaria activities thus reducing the associated costs and fostering the path for MIS implementation in the South East Asia region.

7.4.4.1 Implementation and Operational Cost Estimates of MIS in Indonesia

Initial systems costing for Indonesia has followed the procedure outlined in Chapter 4, section 2, and the conclusions are presented below. A cost breakdown table is included in Appendix E.

The initial costs could be significantly reduced if MIS was to be implemented within the ACTMalaria initiative by sharing parts of the infrastructure and combining training elements between member countries. To optimize coordination and further reduce the initial development budget, the global coordination center should reside within the proposed GIS-Health Data office. Moreover, Indonesia possesses already substantial imaging acquisition and processing software, hardware and a skilled workforce within the national space agency and BAKOSURTANAL organization. Based on the above considerations, one could assume a further reduction of MIS establishment cost between 10 and 30%.

Regarding the dissemination centers, the optimum solution is to use the 240,000 integrated health posts (posyandu) that constitute the national health program local network. These health posts would have to be grouped by geographical location and linked to a single dissemination center. An estimated 2000 to 2400 such centers are considered sufficient to provide national coverage.

It is assumed that images will be provided free of charge by the Indonesian BAKOSURTANAL organization within the system. Processing however will still require personnel, and these wage costs are taken into account in the operational cost of the centers. Indonesia has already a number of ground stations working within the LAPAN, and the cost of the ground stations and the cost of hiring technicians and engineers may be shared.

With an estimated US $5 million start-up cost, implementation of the MIS initiative would require a yearly operational budget of approximately US $2.8 million. However, this figure does not take into account any of the cost mitigation strategies previously outlined (i.e.: ACTMalaria initiative involvement, use of existing facilities, *etc.*) and therefore represents a worst-case scenario. Appropriate expense optimization adoption it is expected to reduce this budget by 10 to 30%.

7.5 Conclusions

These case studies have been designed to exhibit a variety of situations for which the institution of MIS would be beneficial. These countries show a comparatively comprehensive look at how MIS could be implemented across the world, as many of the obstacles are common from country to country.

From the data available, it is apparent that malaria programs in each of the countries have expressed the need for better malaria risk mapping. The information provided by such maps could be used to help concentrate preventative efforts and increase the efficiency of resource use in areas where malaria is not as prominent. Where malaria risk maps exist, they are often out of date and the data can be inefficiently distributed to those who are in need. The MIS program can help alleviate this problem by providing a sound means to gather, process and disseminate much needed information.

Education is also required in order to mitigate the malaria risk. It was shown that not only the health care providers, but also the general population is inadequately educated on how to prevent the spread of malaria. As part of the MIS implementation plan, education will be a major focus. Along with training system users on the basics of how to make use of the MIS, this education can include methods of prevention.

The cost of implementing the MIS varies across the world. Each unique country has different financial capabilities. As was shown, countries such as Kenya and Nigeria, where available funds are scarce, implementation will require assistance. Although limited funds are available, these countries can realize a cost benefit from participating in both macro and micro economic areas. Making a case showing these economic benefits can help convince national leaders and policy makers that the cost of implementing and supporting MIS will be advantageous to the country's further development.

This cost is partially dependant on existing space infrastructure. India was a prime example of how a country with extensive infrastructure can implement the MIS relatively easily. Countries such as Kenya, with its limited space infrastructure, require assistance, but can still participate and reap the benefits.

A variety of other issues will face each country, but the benefits of malaria risk mitigation are promising. Countries can realize a greater productivity level. Most important, the populations of each country will benefit from greater health and security.

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8

Conclusions

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Chapter 8 – Conclusion

8.1 Conclusions and Outlook

Malaria is a devastating and complex disease that continues to plague humankind. Recently, there have been an alarming number of malaria outbreaks and a general resurgence of the disease[1,2]. The fight against malaria requires a variety of strong coordinated efforts in order to substantially reduce the rising incidence of infection and death worldwide. Changes in public health policy, growing insecticide and drug resistance, demographic and societal changes, global climate changes and genetic changes in pathogens are making the fight against malaria more difficult[3]. Thus, malaria prevention is becoming more important than ever. Timely detection of malaria danger zones is essential to assist health authorities and policy makers in determining how to handle malaria resources. In this report, the HI-STAR team has demonstrated that available space technologies and resources can contribute to the fight against malaria providing added benefits to existing initiatives.

Several scientific pilot projects have shown the applicability of space data to identify and map mosquito-breeding sites[4]. Nevertheless, space data and services are not extensively used in the fight against malaria. National, regional and global malaria programs are in place to coordinate the efforts to fight the disease, but an operational global malaria early warning system has not yet been established.

The HI-STAR global strategy suggests the establishment of an active early-warning system. In order to develop this system, the HI-STAR team;

1) Researched the basic characteristics, associated environmental parameters, and emerging global trends for malaria.
2) Described important space technologies that could be used in an early warning system, such as remote sensing satellites, global navigation satellites, and telecommunication satellites.
3) Introduced the Malaria Information System (MIS), potential users, added value, and costs of the system.
4) Identified opportunities and challenges for establishing a dissemination system in developing countries, taking into account technical, political and economic aspects.
5) Reviewed potential users and described an implementation strategy, promotion and funding policies for its development and operation;
6) Examined the current situation regarding the fight against malaria and the available space related resources in Kenya, Nigeria, India and Indonesia and examined a cost-benefit analysis and implementation strategy for using this global strategy.

From this process, the HI-STAR team has developed an early warning strategy to help combat malaria using space technologies and resources. The Malaria Information System is a low cost tool that provides spatial information about the distribution of areas of high malaria risk. The system combines a Geographic Information System based on remotely sensed and ground-based data with existing health information databases. The information gathered would be processed in accordance with local, regional or institutional needs. This information would then be disseminated to the customers using existing or foreseen commercial telecommunication satellites as well as portable autonomous ground segment terminals.

Implementation of the HI-STAR strategy can be executed in a stepwise manner. The first step is development and qualification of the MIS by space agencies. Space agencies could secure funding for a pilot project limited to a few years and to a specific region. For this endeavor, current GIS data can be combined with information from existing programs such as CHAART. Within this pilot project, the potential users of the system such as the World Health Organization would work in close collaboration with the space agencies to ensure the validity and reliability of the system. After successful completion of the pilot project, the

system should be turned over to the users to be operationally included in current efforts. We suggest that the Roll Back Malaria Initiative of the WHO would be an ideal operator of the system with technical assistance from the space agencies. Expansion of the early warning system to cover greater geographical regions should be approached step by step. To assist in creating awareness for our strategy, interdisciplinary conferences or workshops should be organized, bringing together the health community as well as GIS and space experts.

The Malaria Information System is adaptable to the local or regional situation as well as mosquito-specific environmental parameters. Thus, it is also transferable to other vector-borne diseases transmitted by other vectors. For this, the organizational part of the system and its implementation might need to be adapted, because other institutions might be involved, both for operations and financial support.

HI-STAR recommends the increased use of space technology in conjunction with current initiatives. We seek to link the information from space technology to the people who need it most. The HI-STAR team is convinced that our global strategy to implement a malaria early warning system will be an enormous help in the ongoing fight against malaria.

8.2 Conclusion References

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Appendix A

Micro-satellite and Ground-based Sensor Network for Malaria Combat

A.1 Sensor Network on Earth to Detect Anophenline Mosquito

This feasibility study outlines an alternative approach to combating malaria by measuring key parameters of the Anopheles mosquito *in situ*. It is then proposed to transmit these parameters to the Processing Data Center by using a micro-satellite data collection system.

A.1.1 Acoustic Sensors:

Success in fighting malaria will depend upon the ability to predict where the local Anopheles mosquito population is likely to be found. It is proposed to use an Acoustical Sensor Network based on wing beat analysis to detect the number and type of mosquito presence. The mosquito's wing beat analysis including the frequencies, spectrum, pitch, pressure, can yield some important information as follows:

- Male/Female
- Species
- Feed status
- Mating frequency
- Swarms trend
- Results of pesticides control procedures

Swarms of mosquitoes produce sounds that can be detected from 10-50 m at 25-35dB (20μPa) in a quiet environment. The loudness of the swarms is above the 21dB acoustical background between frequencies of 0.6 and 3.4 kHz in an isolated quiet place but below the 40-60dB background of a typical urban environment. In the marsh, females beat their wings at 400-500 Hz and males at >800 Hz, depending on their size and the temperature [1]. These frequency and loudness measurements suggest that it is technologically feasible to construct an acoustical device (or acoustical sensors) for remote surveillance of mosquito swarms [1]. An acoustical sensor usually consists of two closely spaced microphones for the detection of sound intensity.

The sound velocity can be calculated as the difference between the two pressure signals, corrected for the air density and microphone spacing, and then multiplied by the average sound pressure between the two microphones, thus giving the sound intensity. However the individual male and female mosquitoes have low spectrum level (SPL). Acoustical sensors are limited by range, although we can use very sensitive directional microphones to increase range[5]. Moreover a surveillance device based on the sounds of individual mosquitoes would most likely require an attractant source to bring mosquitoes close enough to raise the SPL above the threshold of level [1]. This attractant source may be a "mating call" simulation generator equipped with the sensor, designed to attract the female Anophenline mosquitoes. Alternatively, many pheromone sources exist in commercial mosquito traps.

Acoustical sensors have the advantage of being usable in all types of lighting conditions, whereas optical sensor requires a light source (sunlight or artificial). However this type of

sensitive acoustical sensors is still not available in the marketplace now and needs to be developed to fit within a specific technical requirement of fighting malaria.

A.1.2 Optical Sensors and Neural Network to Detect Mosquitoes

Besides the acoustical sensor networks a neural network and optical sensor was trained to recognize both sexes of mosquitoes [6]. The neural network was given information about the wing beat frequency and correctly classified the insects with a mean accuracy of 98%. Discriminant analysis had provided an accuracy rate of 84% [6]. Even though the mosquitoes were of very similar species, the neural network was successful in distinguishing them. Potential uses for this type of network include:

- population/biological studies
- pollination studies
- evaluation of repellents and attractant
- pest control

Aubrey Moore of the Maui Agricultural Research Station, University of Hawaii, developed this network to assess the feasibility of automatically identifying insects in flight. A photo sensor was used to detect fluctuations in light intensity caused by reflections off individual mosquitoes flying through a light beam.

Digital recording of the photo sensor signals was made with an analog-to-digital recorder. A change in light intensity triggered storage of 512 samples. Each signal was converted to a 256-wide frequency spectrum using a Fast Fourier Transform. One input was assigned for each of the 256 spectrum slices. One output was defined for each of the sex/species combinations for a total of four outputs. The training set used 403 samples, approximately 100 for each sex/species combination. The network was tested on 57 samples. The species and sex of every mosquito in the testing set was identified correctly by the network [6]. Currently, optical sensors can detect mosquitoes up to 500 meters away and within a +/-5 degree angle of sensor orientation but these sensors require a light source (sunlight or artificial)[5]. Photo sensors have been tested in the lab and also in the field but it is difficult to estimate their cost since no companies are producing these sensors commercially at this point [5]. In the long term it may be possible to produce sensors for a selling price of about US $200 each (including software) or they could be even cheaper [5].

A.1.3 RF Path of the Sensors

Each sensor need only collect a relatively small amount of data and therefore a low rate spread spectrum transmitter could be used with good penetrating capabilities in poor visibility areas. This could prove especially useful since sensors may be put under the trees and/or bushes [8]. It shall be assumed that sensors will send data on a weekly basis. Existing systems cannot easily be used in poor operating areas without good visibility direct to the satellite. At this point we should consider two kinds of sensor:

- Transmit-only sensor: we might need to mount a simple GPS receiver (assuming visibility to GPS) that allows for the terminal to calculate when the micro-satellite is in view for its transmissions.

- Transmit and receive sensor: Alternatively a very simple downlink could be used to 'poll' the terminal causing it to transmit. This might help to extend terminal battery lifetime or reduce power required by the terminal. This kind of sensor has some advantages such as: switching the transmission interval from weekly to daily in the case of an epidemic outbreak.

This kind of sensor would be an "intelligence sensor" with some key features such as sensitive to mosquito tracing evidences, reliable in the environment, maintenance free and reasonable in cost. In order to develop these sensors, more research in malaria sites, and statistical data on the habits of the Anopheles mosquito is required. This research should provide a quantitative understanding of mosquito density in surveillance zones. The information coming from the sensors then should be carefully processed and maybe integrated into the GIS or MIS (Malaria Information System) database for later use [2].

A.2 Proposal Segments

A.2.1 Space Segment

Because mosquito data are not required in real time, this means that we could conceivably provide the coverage required with a minimum of one satellite, or perhaps 2 for system level redundancy. The constellation of few satellites in a lower inclination orbit can cover our target areas, in case more than one country participate in this collaboration concept. So we assume to build two micro satellites with some parameters:

- Weight: 50 – 100 kg
- Orbit: LEO
- Frequency: VHF, UHF, S band.
- Modulation mode: spread spectrum.

A.2.2 Ground Segment

Ground station in this system consists of control station and depends upon the satellite manufactures. In case we have more than one party using this system, a network of station should be considered and all parties benefit from increased data capacity, timely command and information access and so on.

A.2.3 System Configuration

The sensor network will be put at sentinel places and/or suspected zones known by the local medical officers. They will collect the mosquito's data and automatically send the data to the micro satellite in weekly basis. The information will be received by the satellite and retransmitted to control center. A processing and analyzing data process will give the mosquitoes parameters, which are useful for GIS, MIS database, decision makers or an alarm signal to local medical office to quickly react to eliminate the potential tragedy of malaria around them.

In addition, it is suggested that should such sensors be placed in rural village communities. In this case, the recorded information on presence of the female anopheles mosquito could be linked to a series of color-coded status lights. As such, villagers could know that if the light is red, that they should use precautionary measures, such as bed nets. And if it is green, they need not spray insecticide, or use prophylactic drugs. Furthermore, local clinics could be advised on the risk, since efficient drug use is critical, yet misdiagnosis remains the greatest cause of malaria deaths.

A.2.4 Potential Utilization of Existing Space Infrastructure

There should be a clear reason for provision of an independent satellite mission. It is possible that this could be because its cheaper than using pre-existing satellite or terrestrial infrastructure, but the upfront cost of designing, building, launching and operating satellites means that invariably it would be cheaper to start at least using a system that is already in place. It might not be possible to use existing systems if the performance required does not

correspond to the existing satellites or if other factors, such as national interests for the use of an independent system. Using a commercial system such as IRIDIUM, GLOBALSTAR or possibly even INMARSAT makes some sense - at least to get moving on an achievable budget.

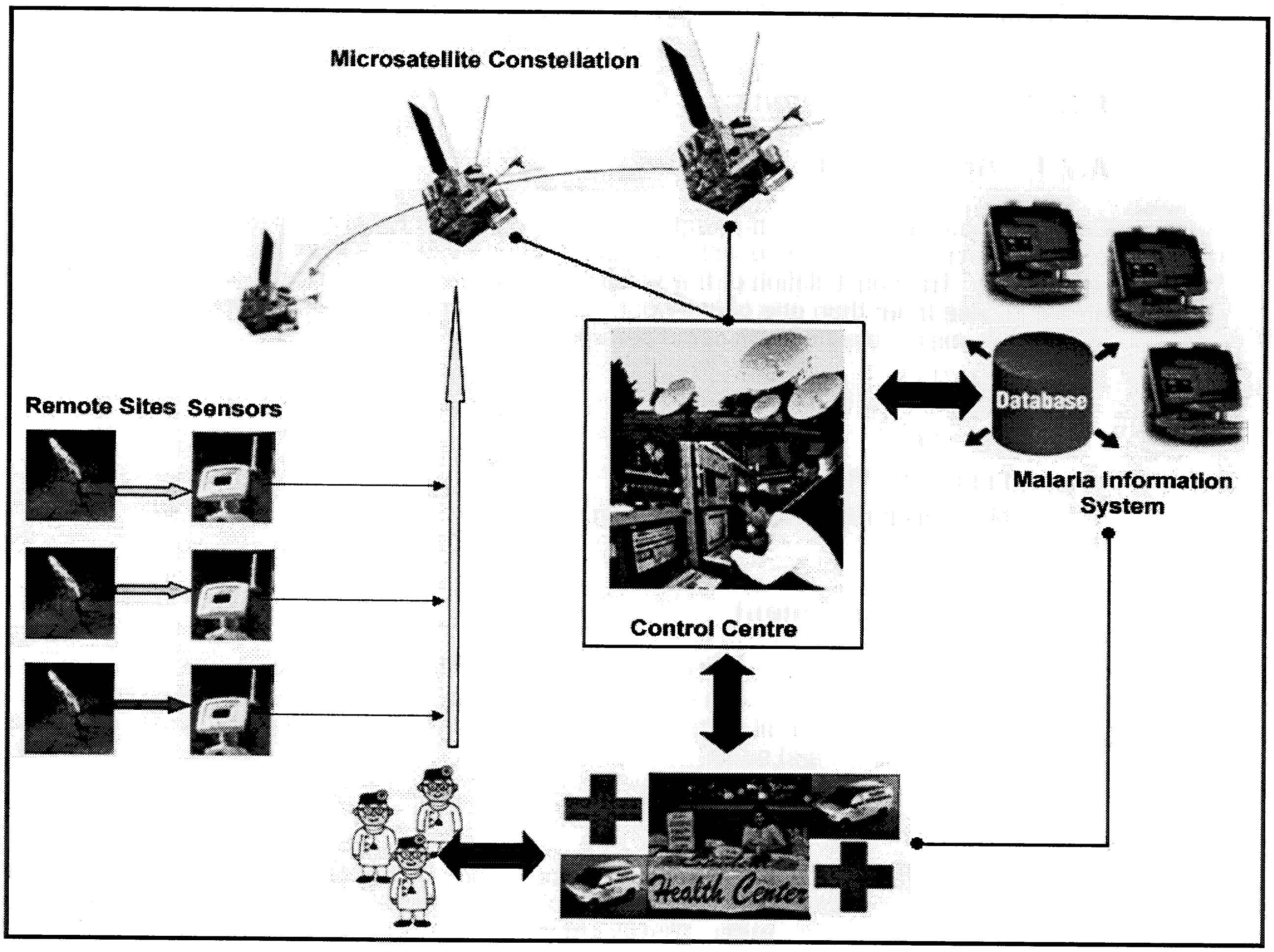

Figure A.1 – Components of the System

A.3 System Estimated Cost

Overall cost of a minimum independent system with a lifetime of 5 years, based upon only 1 or 2 satellites, might possibly be shown to be cheaper than buying and converting existing terminals and paying to use an existing satellite system.

According to a study by Surrey Satellite Technology Ltd. we may assume the following values for a system of two micro-satellites to serve a regional area [8].

Table A.1 – Estimated Costs of System

Cost Component	*US $ (millions)*
Design and payload design activities	3
Platform manufacture and test (x 2)	8
Payload manufacture and test (x 2)	3
Ground control center (equipment only)	0.8
Satellite operations (annual)	0.16
Ground segment design	1
Terminal cost (in quantities of 1000)	0.2
Launch (per satellite as an auxiliary payload)	-
Insurance (per satellite)	-

So we would have to find around 17M USD for building the system excluding the launch price and insurance premium [8]. This budget would come from a mixed mechanism. It is expected that such a system could be financed at least in part by governments, who may be interested in acquiring some space capability, in a similar manner to the Disaster Monitoring Constellation (see appendix G). Because of the meaningful and mutual benefit as the outcome of this project UN, WHO, and other international organization and kindly sponsors play a very important role in financing support and/or donations.

A.4 Conclusions

This is an interdisciplinary initiative combining different fields and needs to be further developed with the support of relevant international organizations and institutions. This concept should be developed as a feasibility study, with special focus on implementation. There are two possible solutions for data transfer. The first is to use existing LEO satellite systems such as Globalstar, Iridium *etc.* An alternative, to develop a new system, should be carefully investigated.

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Appendix B

Metadata and Data Capture

B.1 Metadata

Metadata is information about data, such as content, source, vintage, accuracy, condition, projection, responsible party, contact telephone number, method of collection, and other characteristics or descriptions. Metadata is critical to preserve and protect agencies' spatial data assets. Reliable metadata, structured in a standardized manner, are essential to ensuring that geospatial data are used appropriately, and that any resulting analysis is credible. Metadata also can be used to facilitate the search and access of data sets or geospatial services within a clearinghouse.

B.2 Data Capture

Data capture implies that data can be input into the GIS from existing external digital sources. This is particularly the case when no data exist for a project, and the base data must be assembled from other studies, public domain datasets, and images. The GIS must be able to import the most common data formats both for image-type (raster) and line-type (vector) maps. GIS can capture new map data directly - the user can scan the map and input it into the GIS or trace over a map's features using a digitizing tablet and enter them into the GIS map database. The GIS can accomplish everything that a regular database system can, such as enter and edit data and update information in the existing database.

Vector digital data have been captured as points, lines (a series of point coordinates), or areas (shapes bounded by lines). A GIS to convert data into different formats can perform data restructuring. For example, a GIS may be used to convert a satellite image map to a vector structure by generating lines around all cells with the same classification, while determining the cell spatial relationships, such as adjacency or inclusion. Thus a GIS can be used to analyze land use information in conjunction with property ownership information.

Unlike vector data, raster data are regular arrays of cells without explicit associations with XY coordinates except for one of its corner cells (usually the south west corner). An example would be a satellite image. Increased computer power has made working jointly with vector and raster formats very common. This type of data structure is called hybrid. While it is easy transforming data from one format to another and back, the user has to be aware that the transformation loses information. Some error is introduced into every component of a mapping project. Given the many potential sources of error and the relative magnitude of each, it is critical that accuracy assessment be an integrated component of the MIS. Failure to incorporate the process into the MIS dooms the map to misuse and misinterpretation, and the user to potential trouble.

Once the data is gathered, a variety of choices are available for storing it. This includes hard disk drives, tape storage systems, digital videodisks (DVD), compact disks (CD) and removable storage media. Hard disks, especially Redundant Array of Inexpensive Disks (RAID) is the common used storage system, because they have long served as very convenient fast access means for storing data. Tape storage drives have improved over time and they are primarily used for permanent backup storage.

Appendix C

Data Providers for UN Environmental Program (UNEP) Data Portal

Table C.1 – Data Providers

Carbon Dioxide Information Analysis Center (CDIAC)
Center for International Earth Science Information Network (CIESIN)
Environmental Systems Research Institute (ESRI)
Food and Agriculture Organization of the United Nations (FAO)
Forest Stewardship Council (FSC)
Global Resource Information Database, Arendal (GRID-Arendal)
Global Resource Information Database, Geneva (GRID-Geneva)
Global Resource Information Database, Sioux Falls (GRID-Sioux Falls)
International Soil Reference and Information Centre (ISRIC)
International Union for the Conservation of Nature (IUCN - The World Conservation Union) (IUCN)
International Energy Agency (IEA)
National Institute for Public Health and the Environment (RIVM)
NOAA National Geophysical Data Center (NOAA/NGDC)
Office of U.S. Foreign Disaster Assistance / The Centre for Research on the Epidemiology of Disasters (OFDA/CRED)
Organization for Economic Co-operation and Development (OECD)
The Ramsar Convention on Wetlands
The World Bank
The World Fish Centre
UNEP - The World Conservation Monitoring Center (WCMC)
UNEP/WMO Intergovernmental Panel on Climate Change / Data Distribution Centre (DDC)
United Nations Development Programme (UNDP)

United Nations Educational, Scientific and Cultural Organization (UNESCO)
United Nations Environment Programme Ozone Secretariat
United Nations Framework Convention on Climate Change (UNFCCC)
United Nations Human Settlements Programme (UN-HABITAT)
United Nations International Children's Emergency Fund / Children's Fund (UNICEF)
United Nations International Labour Organization (ILO)
United Nations International Telecommunications Union (ITU)
United Nations Population Division
United Nations Statistics Division (UN-STAT)
United Nations World Health Organization (WHO)
United States Geological Survey - EROS Data Center (EDC)
US-DOI United States Geological Survey (USGS)
World Resources Institute (WRI)
World Energy Council - Conseil Mondial de l'Energie (WEC)
World Wildlife Fund (WWF)

Source: http://geodata.grid.unep.ch/datasource.htm
Accessed on 22 August 2002.

Appendix D

Information Dissemination Services Offered By World Space and Vita

D.1 The World Space Foundation

World Space Foundation is a publicly supported nonprofit organization headquartered in Washington, DC, USA. World Space uses its satellites to deliver: audio, data casting, and distance education. Their mission is to help improve the lives of disadvantaged people in developing regions of the world by providing access to education and other information broadcast directly to radios from satellites.

Endowed with 5% capacity on the satellites of the World Space system, World Space Foundation (WSF) works with local and international non-governmental organizations (NGOs), national and intergovernmental agencies, and a variety of community groups to produce and deliver social development and education programs to communities in the developing world that are disadvantaged by poverty, illiteracy, inadequate infrastructure, and geographical isolation. The foundation looks to grants, donations, corporate funding, other foundations, and government sponsored programs as sources of support.

There are three basic services offered on the World Space satellite namely:
Audio, Datacasting and Distance Education, these three services are applicable to MIS as a means of information dissemination, a critical look at the data casting and Distance Education services are given below.

D.2 Volunteers in Technical Assistance (VITA)

For over four decades VITA has empowered the poor in developing countries by providing access to information and knowledge, strengthening local institutions and introducing improved technologies. Its particular focus is on support to entrepreneurs in the private, public and community sectors and on facilitating connectivity and technical information exchange between and among individuals and organizations.

Since 1982 VITA has pioneered communication for rural development through the use of low earth orbiting (LEO) satellite access. Now VITA is launching the VITA-CONNECT network. VITA-CONNECT will provide humanitarian organizations and the communities they serve with an affordable solution for basic e-mail connectivity and a unique, low-bandwidth link to the VITA information services portal from anywhere in the world.

Appendix E

Cost Tables

Appendix E presents the MIS investment cost and operation cost in each country discussed in Chapter 7. For convenience the equations with the cost build-up are repeated here. The rationale behind the approach is given in Chapter 4. Detailed information on the situation in each country is given in tables E.1 to E.4. The tables show that investment and operation costs depend heavily upon the size of the country and the available infrastructure.

Investment cost equation

$$I_{Cost} = C_{Development} + C_{CoordinationCenter} + n_1 \cdot C_{RegionalCenter} + n_2 \cdot C_{ExistingRegionalCenter} + n_3 \cdot C_{DisseminationPoint}$$

where

I_{Cost}	=	Cost of initial investment
$C_{Development}$	=	MIS development cost
$C_{CoordinationCenter}$	=	Initial investment cost to start an office
n_1	=	Number of new regional centers (ground stations) needed
$C_{RegionalCenter}$	=	Initial investment cost of regional center
n_2	=	Number of existing regional centers used in the MIS network
$C_{ExistingRegionalCenter}$	=	Initial investment cost to implement MIS in an existing regional center
n_3	=	Number of dissemination points
$C_{DisseminationPoint}$	=	Initial investment cost of a dissemination point (including the start-up cost for training local people)

Operation cost equation

$$R_{annual} = R_{Depreciati\ on} + R_{Datacost} + R_{Datalink} + m_1 \cdot R_{MISCenter} + m_2 \cdot R_{SharedRegi\ onalCenter} + m_3 \cdot R_{Disseminat\ ionPoint} + S_{Coordinati\ on}$$

where

$R_{Depreciation}$	=	Depreciation costs of initial investment (linear 10 year)
$R_{DataCost}$	=	Cost of updating data
$R_{Datalink}$	=	Data link cost
m_1	=	Number of MIS centers (not shared)
$R_{RegionalCenter}$	=	Recurring cost of a MIS regional center (not shared)
m_2	=	Number shared existing regional centers used in the MIS network
$R_{ExistingRegionalCenter}$	=	Recurring cost an existing (shared) regional center
m_3	=	Number of dissemination points
$R_{DisseminationPoint}$	=	Recurring cost of a dissemination point (including recurring cost for training local people)
$S_{Coordination}$	=	Share (10%) of the cost of a global co-ordination center

Table E.1 – Total Cost Table for Kenya

Initial Investment Cost		*Comments*
Cdevelopment	$300,000	
Ccoordination	$35,000	
Cregional_l	$620,000	To be built
Cexistingregional	$80,000	
Cdissemination	$1,700	
n_1 (new)	2	
n_2 (shared)	2	
n_3	307	
Investment Cost	**$2,256,900**	**ROM $ 2.3 Million**
Operating Cost		
Depreciation Initial Investment	$225,690	
Rdata	$0	
Rdownlink	$0	
RMIScentre	$22,000	
Rsharedcentre	$10,000	
Rdissemination	$500	
Sglobalcentre	$110,000	
m_1 (not shared)	2	
m_2 (shared)	2	
m_3	307	
Annual Cost	**$721,190**	**ROM $ 0.7 Million**

Table E.2 – Total Cost Table for Nigeria

Initial Investment Cost		*Comments*
Cdevelopment	$300,000	
Ccoordination	$35,000	
$Cregional_l$	$620,000	To be built
Cexistingregional	$80,000	
Cdissemination	$1,700	
n_1 (new)	2	
n_2 (shared)	2	
n_3	1266	
Investment Cost	**$3,887,200**	**ROM $ 3.9 Million**
Operating Cost		
Depreciation Initial Investment	$388,720	
Rdata	$4,200	
Rdownlink	$0	
RMIScentre	$22,000	
Rsharedcentre	$10,000	
Rdissemination	$500	
Sglobalcentre	$110,000	
m_1 (not shared)	2	
m_2 (shared)	2	
m_3	1266	
Annual Cost	**$1,363,720**	**ROM $ 1.4 Million**

Table E.3 – Total Cost Table for India

Initial Investment Cost		*Comments*
Cdevelopment	$300,000	
Ccoordination	$35,000	
$Cregional_l$	$620,000	
Cexistingregional	$80,000	
Cdissemination	$1,700	
n_1 (new)	0	
n_2 (shared)	15	
n_3	7,500	
Investment Cost	**14,285,000**	**ROM $ 14 Million**
Operating Cost		
Depreciation Initial Investment	$1,428,500	
Rdata	$0	Data is free available in India
Rdownlink	$0	
RMIScentre	$22,000	
Rsharedcentre	$10,000	
Rdissemination	$500	
Sglobalcentre	$110,000	
m_1 (not shared)	0	
m_2 (shared)	15	
m_3	7,500	
Annual Cost	**$5,438,500**	**ROM $ 5.4 Million**

Table E.4 – Total Cost Table for Indonesia

Initial Investment Cost		*Comments*
Cdevelopment	$300,000	
Ccoordination	$35,000	Existing
Cregional	$620,000	To be built
Cexistingregional	$80,000	
Cdissemination	$2,000	To be built (tel/fax/internet/TV)
n_1 (new)	0	Indonesia has already processing capabilities available
n_2 (shared)	4	4 new regional centers
n_3	2200	Number of dissemination centers
Investment Cost	**$5,055,000**	**ROM $5 million**
Operating Cost		
Depreciation Initial Investment	$505,500	
Rdata	$0	Ground stations owned by Indonesia
Rdownlink	$0	Communications satellites exist
RMIScentre	$0	
Rsharedcentre	$5,000	2 qualified people
Rdissemination	$1,000	1 unqualified person
Sglobalcentre	$110,000	
m_1 (not shared)	0	
m_2 (shared)	4	
m_3	2200	
Annual Cost	**$2,835,500**	**ROM $2.8 million**

Appendix F

Existing Satellite Technologies

Appendix F lists the existing relevant remote sensing satellites that can be used to monitor or map environmental land use. Specifically, Table F.1 lists the existing NASA satellites, Table F.2 lists other space agency satellites, Table F.3 lists India's satellites, and Table F.3 lists all other relevant EOS.

For each satellite, instrument identification, resolution and swath width data is presented. More importantly, the differing capability of each satellite in terms of spectral data type is presented. As outlined in Chapter 2, the main ecological parameters for malaria distribution are as follows

- Deforestation, represented by D
- Flooding, represented by F
- Soil Moisture, M
- Rainfall, R
- Stagnant Water, S
- Temperature, T
- Vegetation Green-up, Vg
- Vegetation crop-type, Vc
- Wetlands, W

In the following tables, a shaded box indicates that the satellite is capable of sensing that particular type of data.

As well it should be noted that the spectral resolution is represented by one of the following acronyms

- VNIR – Very Near InfraRed
- SWIR – Short Wavelength InfraRed
- TIR – Thermal InfraRed
- RIR – Resonant InfraRed
- PAN – Panchromatic
- SAR-C – Synthetic Aperture Radar, C-Band

The data in this appendix was obtained from Herbert J. Kramer 'Observation of the Earth and Its Environment', published by Springer, 2002

Table F.1 – NASA Earth Observation / Monitoring Missions

Satellite	*Provider/ Operator*	*Year of Launch*	*Instrument*	*Resolution*			*Swath Width (km)*	D	F	M	R	S	T	Vg	Vc	W
				Spatial (m)	*Spectral*	*Temporal (days)*										
Terra (EOS)	NASA	1999	ASTER	15	VNIR	16	60									
				20	SWIR	16										
				90	TIR	16										
			MISR	250	VNIR	2-9	360									
			MODIS	250	RIR	2	2330									
				500	VNIR	2										
				500	SWIR	2										
				1000	VNIR	2										
				1000	SWIR	2										
				1000	TIR	2										
Landsat	NASA	1984	TM	30	VNIR	16	185									
				30	SWIR	16										
				120	TIR	16										
Landsat-7	NASA	1999	ETM+	15	PAN	16	185									
				30	VNIR	16										
				30	SWIR	16										
				60	TIR	16										

Table F.2 – Other Space Agency (except India) Earth Observation / Monitoring Missions

Satellite	Provider/ Operator	Year of Launch	Instrument	Resolution			Swath Width (km)	D	F	M	R	S	T	Vg	Vc	W
				Spatial (m)	Spectral	Temporal (days)										
CBERS	CAST/ INPE	1999	CCD	20	VNIR	26	113									
				20	PAN	26										
			WFI	260	RIR	3-5	885									
			IR-MSS	80	PAN	26	120									
				80	SWIR	26										
				160	TIR	26										
ERS-1	ESA	1991	AMI-SAR	30	SAR-C	26	100									
ERS-2	ESA	1995	AMI-SAR	30	SAR-C	16-35	100									
			ATSR-2	1000	RIR	16-35	-									
PSIRODA	RKA	1996	MSU-SK	120-300	VNIR	16-35	320									
			MOMS-2P	6	VNIR	14	50-105									
				16	SWIR	14										
RADARSAT	CSA	1995	-	10-100	SAR-C	14	10-500									
RESURS-01	Planeta	1994	N3 MSU-SK	170	TIR	2-4	600									
				600	VNIR	2-4										
RESURS-02	Planeta	1998	MSU-SK	170	TIR	2-4	600									
				600	VNIR	2-4										
SPOT2	CNES	1990	2xHRV	20	VNIR	26	60-80									
SPOT4	CNES	1998	2xHRVIR	20	VNIR	3	60									
				20	SWIR	3										
			-	1000	VNIR	1	2200									
				1000	SWIR	1										

Table F.3 - India Earth Observation / Monitoring Missions

Satellite	*Provider/ Operator*	*Year of Launch*	*Instrument*	*Resolution* *Spatial (m)*	*Spectral*	*Temporal (days)*	*Swath Width (km)*	D	F	M	R	S	T	Vg	Vc	W
IRS-1A	NNRMS	1988	LISS1	72	VNIR	22	148									
			LISS2	36	VNIR	22										
IRS-1B	NNRMS	1991	LISS1	72	VNIR	22	148									
			LISS2	36	VNIR	22										
IRS-P2	NNRMS	1994	LISS2	36	VNIR	24	131									
IRS-1C	NNRMS	1995	LISS3	23	VNIR	24	142									
				70	SWIR	24										
			WiFS	188	VNIR	5-24										
IRS-1D	NNRMS	1997	LISS3	23	VNIR	24	804									
				70	SWIR	24										
			WiFS	188	VNIR	5-24										
				188	SWIR	5-24										
IRS-P3	NNRMS	1996	MOS	500	VNIR	5	-									
			WiFS	188	VNIR	5										
				188	SWIR	5										
IRS-P4	NNRMS	1999	OCM	360	VNIR	2	1420									

Table F.4 - Other Earth Observation / Monitoring Missions

Satellite	*Provider/ Operator*	*Year of Launch*	*Instrument*	*Resolution*			*Swath Width (km)*	D	F	M	R	S	T	Vg	Vc	W
				Spatial (m)	*Spectral*	*Temporal (days)*										
IKONOS	Lockheed Martin	1999	-	4	VNIR	11	12.2									
ORBVIEW -2	Orbital Imaging Co.	1997	SeaWiFS	1100-4500	VNIR	1-2	45-58.3 deg									
NOAA-10	NASA	1985	AVHRR	1100	RIR	0.5	2348									
				1100	SWIR	0.5										
				1100	TIR	0.5										
NOAA-11	NASA	1998	AVHRR	1100	RIR	0.5	2348									
				1100	SWIR	0.5										
				1100	TIR	0.5										
NOAA-14	NASA	1994	AVHRR	1100	RIR	0.5	2348									
				1100	SWIR	0.5										
				1100	TIR	0.5										

Appendix G

Micro-Satellite Option

G.1 Micro-Satellites: An Alternative?

Small satellites have established themselves in the spectrum of mission opportunities as alternatives to the traditionally big missions. While the latter are plagued with long lead times, low mission frequency and high costs, small satellite missions can be innovative, flexible and cheaper[1]. Conventional Earth observation and remote sensing satellite missions typically cost over UK £150 million each. Consequently there are relatively few such missions and the resulting data is correspondingly expensive. The development of high-density two-dimensional semi-conductor Charge-Coupled Device optical detectors, together with low-power consumption yet computationally powerful microprocessors, presents a new opportunity for remote sensing using inexpensive small satellites[2].

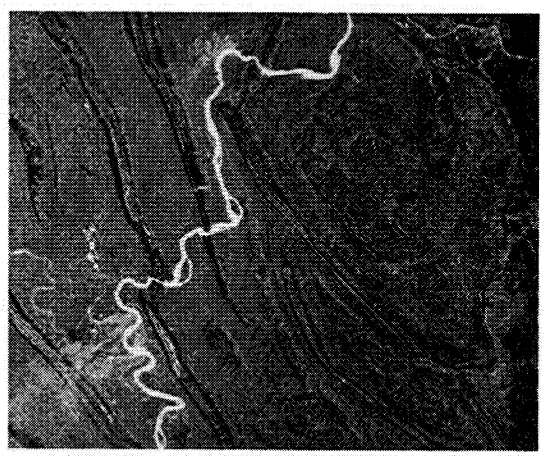

Image taken by TMSAT, owned and operated by the Thai Micro-satellite Company, Bangkok, Thailand. TMSAT was designed and built by SSTL.

Figure G.1 - The Yangze River at Chongging, China

Micro-satellites typically weigh between 50kg - 100kg, and generate approximately 30W. Smaller satellites offer shorter development times, on smaller budgets and can fulfill many of the functions of their larger counterparts. As micro-satellites can benefit from leading edge technology, their design lifetime is often more limited by the rapid advances in technology rather than failure of the onboard systems. A perfect example of this is the Digital Store and Forward satellite UoSAT-2 launched in 1984, which is still operational in 1995. The micro-satellite weighs 61kg and was developed for approximately US $1 million[3]

Micro-satellite missions such as Topsat[4] aim to demonstrate that sophisticated Earth Observation capabilities can be provided at a fraction of conventional costs. Surrey Satellite Technology Ltd (SSTL) of the UK is the world leader in cost effective micro satellites, and has acted as contractor for a number of countries seeking to develop space capabilities.

G.2 Micro-Satellite Collaboration Model

The Disaster Monitoring Constellation (DMC) is an International Collaboration born of the UNISPACE III proceedings in 1999. The conference concluded that small satellites offer cost advantages that are particularly attractive to "Space-emerging" nations, whereby the small satellites can be developed through international co-operations, allowing also the opportunity to train a base of engineers and scientists in satellite design[5].

The DMC has been proposed and is led by SSTL of the UK, and is intended to construct a network of seven micro-satellites in Low Earth Orbit to provide daily imaging for rapid response disaster monitoring and mitigation. A constellation of conventional Earth Observing satellites capable of daily revisit imaging worldwide would certainly be prohibitively expensive, even for developed space nations. The DMC will incorporate highly capable 100 kg micro-satellites providing multi-spectral imaging at 1/50th the conventional cost[6]. Processed images from the DMC will be distributed to relief teams by the Reuters AlterNet Foundation. This constellation involves seven countries: Algeria, China, Nigeria, Thailand, Turkey, UK and Vietnam. Each member agrees to purchase one dedicated micro-satellite under a Technology Transfer and Training (TT&T) program, and to make available its data to the other members of the constellation. As part of the TT&T and for a cost of approximately US $15 million, a member state can send engineers to the UK to follow academic programs, where SSTL designs and builds their proto-type micro-satellite with them, then constructs the ground stations in the member country, and finally constructs the actually micro-satellite in that country. In this way, space-emerging nations acquire a sustainable space capability, at a very affordable cost. The model for cooperation in space that the DMC presents has been very successful, and the entire constellation is planned to be operational by end of 2003[7], only four years after its inception.

G.3 Ground Stations Applicable for Microsatellite Mission

The usage of microsatellites in LEO has an important role on Earth observation and the related communication. However, the problem is that the duration of communication limited, unlike GEO satellites. SSTL solved such a problem by establishing the groundstation network.

Figure G-1 shows the ground stations that have been installed by SSTL to support particular microsatellite missions. Figure G.2 is one ground station using UHF/VHF bands. All ground stations in various countries are installed as a part of the TT&T.

One DMC satellite will transit one ground station in passes for 10-15 minutes. Typically, 8-9 passes are seen per satellite in a 24-hour period. However, it is not enough time to download a large amount of data from the satellite.

Therefore, by networking the other stations of the DMC together with the Surrey Mission Operations Centre, all parties benefit from increased data capacity, timely command access, regular telemetry acquisition, and failure resilience. The ground station network provides the infrastructure required to commission and operate the DMC. However, the ground stations should connect with each other by LAN.

SSTL's Low Earth Orbit Satellite Communications Terminal (SCT) provides digital store-and-forward communications from a compact desktop or field station (User Ground Station). It is ideal for civil or military message file transfer and remote site data collection and remote control applications - on land or sea. Easy to use, the SCT is powered by an internal battery for fully portable operation.

"Digital Store-and-Forward Communications" is the communication strategy by SSTL. The procedure is the following. See figure G.3.

1. The microsatellite uploads email-like information from a terminal on the ground site A using amateur bands (UHF-, VHF-bands).
2. The microsatellite flies on its orbit.
3. When the microsatellite passes over an inexpensive fixed ground site B which is necessary to get the information from the ground site A, download is performed from the satellite to B.

As the above, ground stations are categorized as the following two: (1) Networking Ground Station and (2) User Ground Station. Networking Ground Station supports mainly the following three: (a) store and forward communications, (b) reception of Earth images, and (c) Reception and analysis of telemetry and experiment data. On the other hand, User Ground Station has a role on (a).

In order to perform (c), Networking Ground Stations offer a high degree of autonomy, and do not require operators to be present on a continuous basis. The standard groundstation comprises a tower with tracking VHF and UHF antennas, a VHF/UHF transceiver, modems and Terminal Node Controllers, and computers.

The data rate of the uplink is fixed at 9.6kbps with VHF-band or 128kbps with S-band. In the case of downlink, the rate is fixed at 9.6kbps with UHF-band or 2Mbps with S-band.

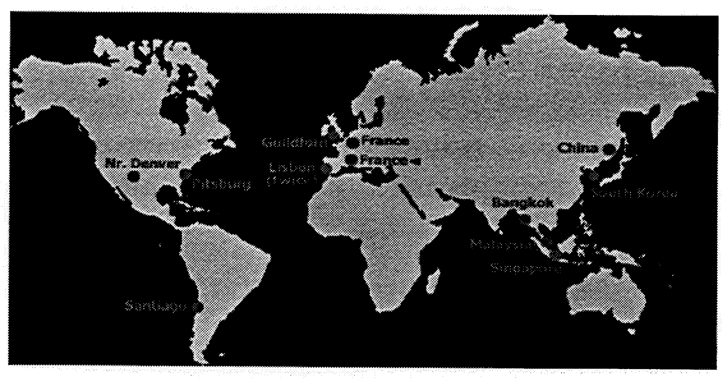

Figure G.2 – SSTL ground stations network
(Source: www.sstl.co.uk)

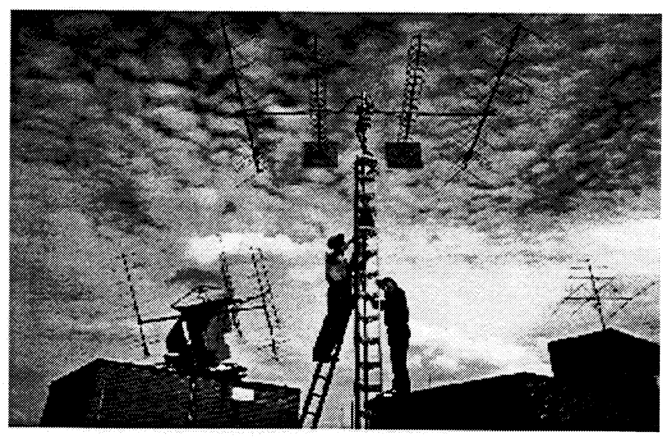

Figure G.3 – SSTL ground stations network
(Source: www.sstl.co.uk)

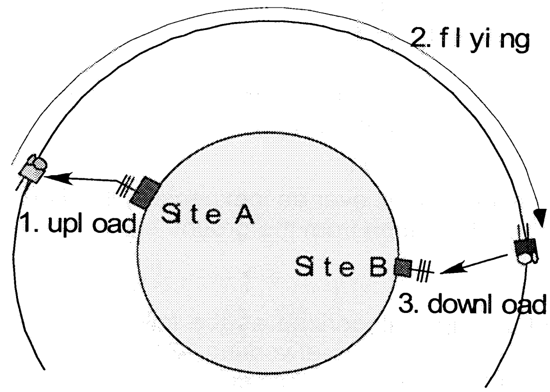

Figure G.4 – Digital Store-and-Forward Communications

G.4 References

[1] Rabenau, Fischer, Klein. 1996. "*More Spaceflight for Less Money - Results of the DARA Workshop on Mission Operations Concepts For Small Satellites*", Proceedings, Fourth International Symposium on Space Mission Operations and Ground Data Systems, DARA.

[2] Sweeting, M. 2002. Surrey Satellite Technology Limited, online at: http://www.sstl.co.uk/services/subpage_services.html (last accessed 25/08/02)

[3] Fleeter, R., Warner, R., 1992, "Design of Low Cost Spalcecraft", in Larson, W. J., Wertz, J. R. (ed.), *Space Mission Analysis and Design*, 2nd ed., Microcosm Inc., CA, USA: Microcosm, Inc. at 787

[4] Surrey Satellite Technology Ltd. 2002: "Satellite Missions: Topsat" online at: http://www.sstl.co.uk/missions/subpage_missions.html (last accessed 26/08/02)

[5] Third United Nations Conference of the Exploration and Peaceful Uses of Outer Space, 26th May 1998. "*Small Satellite Missions: Background Paper 9*". United Nations Office of Outer Space Affairs, Vienna, Austria.

[6] SSTL: "*Surrey Space news letter*" (Summer 2001), Guilford, UK.

[7] SSTL: "International Disaster Monitoring Microsatellite Constellation Forges Ahead" (8th May 2002), Guilford, Surrey, UK online at : http://www.sstl.co.uk/news/subpage_news.html

Appendix H

Micro-Satellite Option

H.1 Roll Back Malaria: Indicative Strategic Resource Gap by Country[1]

Table H.1 – Indicative Strategic Resource Gap by Country (all figures in US$)

Burkina Faso	**Year 1**	**5-year total**
Total Budget	3,377,141	12,485,711
Pledges	Pledges not yet processed	Pledges not yet processed
Gap	-	-
✗ Round Table has not taken place.		
Eritrea	**Year 1**	**5-year total**
Total Budget	10,483,849	42,725,853
Pledges	7,000,000	(7m for year 1)
Gap	3,483,849	35,725,853
Ethiopia	**Year 1**	**5-year total**
Total Budget	20,905,920	122,037,434
Pledges	2,552,400	(2,552,400)
Gap	18,535,520	119,485,034
✗ Year one pledge from government is 2,552,400.		
Ghana	**Year 1**	**5-year total**
Total Budget	2,995,140	12,371,900
Pledges	1,800,000	(1,800,000)
Gap	1,195,140	11,767,040
Kenya	**Year 1**	**5-year total**
Total Budget	16,900,000	84,500,000
Pledges	990,000	(990,000)
Gap	15,910,000	83,510,000
✗ Total budget for five years is an RBM estimate (assuming level expenditure).		
Mali	**Year 1**	**5-year total**
Total Budget	3,145,376	43,543,522
Pledges	–	–
Gap	–	–
✗ Round Table has adopted the strategy, but has not advanced to pledging.		

Nigeria	Year 1	5-year total
Total Budget	55,600,000	204,800,000
Pledges	5,405,000	(5,405,000)
Gap	50,195,000	199,395,000

Senegal	Year 1	5-year total
Total Budget	6,363,625	38,489,377
Pledges	—	—
Gap	—	—

x Round Table has adopted the strategy, but has not advanced to pledging

Sudan	Year 1	5-year total
Total Budget	16,791,562	83,957,810
Pledges	4,380,000	(4,380,000)
Gap	12,411,562	79,577,810

x Total budget for five years is an RBM estimate (assuming level expenditure).

Togo	Year 1	5-year total
Total Budget	876,604	8,994,870
Pledges	159,000	(159,000)
Gap	717,604	8,835,870

Zambia	Year 1	5-year total
Total Budget	9,142,500	33,408,000
Pledges	8,342,000	28,842,000
Gap	800,500	4,566,000

Zimbabwe	Year 1	5-year total
Total Budget	2,991,000	7,157,000
Pledges	1,038,000	(1,038,000)
Gap	1,953,000	6,119,000

x Total budget for five years is an RBM estimate (assuming level expenditure).

H.2 Main Actors

H.2.1 International Organizations

International organizations have the expertise in carrying international programs. They have proved to be effective and guarantee support all along the duration of the program. Moreover states are member of these organizations, which consequently have a privileged relation with, or at least an easier access to national institutions. Finally programs carried by international organizations benefit from the notoriety of the organizations.

MIS combines health and technological issues. Thus, it could be implemented within the World Health Organization (WHO) or the World Meteorological Organization (WMO). WMO aims at facilitating international cooperation to establish networks of stations making meteorological, hydrological and other observations and at promoting the rapid exchange of meteorological information and the standardization of those. WHO's aim is to improve human health worldwide and it carries a number of programs towards the combat of malaria (see section 6.1). Both organizations are United Nations specialized agencies and count more than 180 Member States.

Other organizations might also be concerned such as the United Nations Development Program or the World Bank. These organizations participate in the combat of malaria through different initiatives (RBM, Global Fund, MIM, TDR) although none of them is specifically in charge with the technical, medical or political aspects of malaria.

H.2.2 International non governmental organizations (NGOs)

NGOs play an important role in the combat of malaria. They are, for example, part of the RBM initiative and are represented in the Board of the Global Fund. The advantage of having an NGO leading an international program is that they should be more independent that other organizations as no political pressure can be made upon them. On the other hand, they depend very much for their financing on donations. Thus their financing is not always secured.

H.2.3 Regional organizations

Global programs can also be carried by regional organizations. A good example is the Global Monitoring for Environment and Security (GMES), a joint initiative of the European Commission and the European Space Agency (ESA). GMES has been designed to ensure continuous access to high-quality information services on environment and security issues. The Commission is responsible for the policy aspects and ESA for the technical implementation. The success of GMES will depend largely upon a close cooperation between these two institutions.

MIS could also be implemented as a joint program of a regional policy and regulatory body and a regional space related institution. However this solution would require solidly coordinated institutions for both aspects and unfortunately the main regions of implementation of MIS, *i.e.* Africa and Asia, do not presently offer any kind of institutional framework with such a level of integrated cooperation as the one already existing in Europe.

H.2.4 National Institution

National institutions such as health ministries and other health or technical agencies, could be implementing MIS. In principle, they should have a better understanding and expertise of the combat of malaria. Nonetheless they may not be the best fitted to be the principal implementing institution for MIS. Countries might be subject to political instability that will render the provision and maintenance of the service difficult. Moreover MIS will provide a global service; therefore a coordinated management at a global scale would be preferable. Countries may also just lack the resources required to implement MIS or refuse to take the financial burden of a service that will be shared with other countries.

H.3 MIS Implementation - Funding

Funding, or the lack thereof, of programs combating Malaria has been cited as a major impediment. Consequently, HI-STAR will seek funding from various international sources. Depicted below are some of the funding sources that could prove fruitful for the development and implementation of the Malaria Information System (MIS).

H.3.1 MIM/TDR Grant

In July 1997, a multilateral funding mechanism was established by the UNDP/World Bank/WHO for Research and Training in Tropical Diseases (TDR) to address research and develop a sustainable malaria research capacity in Africa. As a result, the MIM/TDR Task Force was established to manage partnership proposals. The Task Force promotes human resource development by supporting research activities in endemic countries. The goal is to develop products and mechanisms relevant to the understanding of the occurrence, distribution and control of malaria in Africa. TDR's role in MIM is to assess the scientific needs and take responsibility for strengthening the research capacities of malaria-endemic countries in Africa.

TDR coordinates the Task Force, which represents collaboration between a number of agencies and governments for promoting capacity building activities in the context of the MIM. The Capability Strengthening Grant for Malaria research in Africa (MIM/TDR Grant) provides support to core African research groups for the development of malaria control tools. The aim is to promote partnerships, collaboration, technology transfer and training opportunities through research projects and networks in malaria endemic counties.

In order to apply for a MIM/TDR Grant, an African national scientist working in a research group in Africa must submit and coordinate the application[2].

H.3.2 The Global Fund to Fight AIDS, Tuberculosis & Malaria

The Global Fund to fight AIDS, Tuberculosis and Malaria was established in June 2001 with Declarations and financial commitments in the UN General Assembly Special Session on HIV/AIDS in June 2001 and at the G8 Summit in Genoa. They have a Technical Review Panel (TRP), which reviews proposals submitted for funding and then makes recommendations to the Board of the Global Fund for final funding decisions. The Fund gives priority to effective proposals from countries and regions with the greatest need, based on highest burden of disease and the least ability to bring financial resources to address the problems of AIDS, tuberculosis and malaria.

"The principles underlying the Fund:

- The Fund is a financial instrument, not an implementing entity.
- The Fund will make available and leverage additional financial resources to combat HIV/AIDS, tuberculosis and malaria.
- The Fund will base its work on programs that reflect national ownership and respect country-led formulation and implementation processes.
- The Fund will seek to operate in a balanced manner in terms of different regions, diseases and interventions.
- The Fund will pursue an integrated and balanced approach covering prevention, treatment, and care and support in dealing with the three diseases.
- The Fund will evaluate proposals through independent review processes based on the most appropriate scientific and technical standards that take into account local realities and priorities.

- The Fund will seek to establish a simplified, rapid, innovative process with efficient and effective disbursement mechanisms, minimizing transaction costs and operating in a transparent and accountable manner based on clearly defined responsibilities. The Fund should make use of existing international mechanisms and health plans.

  In making its funding decisions, the Fund will support proposals which:

- Focus on best practices by funding interventions that work and can be scaled up to reach people affected by HIV/AIDS, tuberculosis, and malaria.
- Strengthen and reflect high-level, sustained political involvement and commitment in making allocations of its resources.
- Support the substantial scaling up and increased coverage of proven and effective interventions, which strengthen systems for working: within the health sector; across government departments; and with communities.
- Build on, complement, and co-ordinate with existing regional and national programs (including governments, public/private partnerships, NGOs, and civil society initiatives) in support of national policies, priorities and partnerships, including Poverty Reduction Strategies and sector-wide approaches.
- Focus on performance by linking resources to the achievement of clear, measurable and sustainable results.
- Focus on the creation, development and expansion of government/private/NGO partnerships.
- Strengthen the participation of communities and people, particularly those infected and directly affected by the three diseases, in the development of proposals.
- Are consistent with international law and agreements, respect intellectual property rights, such as Trade-Related Aspects of Intellectual Property Rights (TRIPS), and encourage efforts to make quality drugs and products available at the lowest possible prices for those in need.
- Give due priority to the most affected countries and communities, and to those countries most at risk.
- Aim to eliminate stigmatization of and discrimination against those infected and affected by HIV/AIDS, especially for women, children and vulnerable groups."

A well-managed fund of significant size can have a multiplier effect in many ways: by helping to create the conditions at country level that will enable other donors to increase their level of spending on health and development; by giving political prominence to the importance of achieving better outcomes in HIV/AIDS, malaria and tuberculosis; and by demonstrating to donors and national governments the benefits to be achieved by linking funding to better results.

The TWG will seek to establish a bank account as soon as possible to allow governments to fulfill their pledges. A bank account for private donations already has been established by the United Nations Foundation. To date, pledges to the Global Fund from government and private contributions amount to more than US $2 billion[3].

H.3.3 Bill and Melinda Gates Foundation

The Bill and Melinda Gates Foundation has as its main goal to improve people's lives by sharing advances in health and learning with the global community. The foundation was founded in January of 2000, through the merger of the Gates Learning Foundation and the William H. Gates Foundation. The foundation has an endowment of approximately US $24 billion.

The Bill and Melinda Gates Foundation and the scientific community state that the causes, clinical course and keys to prevention of malaria are well understood. However, it believes

that patients are suffering because of inadequate implementation of this knowledge. According to the Bill & Melinda Gates Foundation, winning the battle against Malaria can be accomplished if efforts are made on multiple fronts: mosquito control, rapid and complete treatment of patients, production of new drugs targeting resistant strains, and development of an effective vaccine. Consequently, the Bill and Melinda Gates Foundation has contributed over US $125 million to researchers and physicians working in these areas that are fighting Malaria. This funding is allowing for collaboration among groups to build a united force against malaria.

The Bill and Melinda Gates Foundation considers grant requests in the form of a Letter of Inquiry, and it favors preventive approaches and collaborative endeavors. Priority is given to grants that serve as a catalyst for long-term, systemic change [4].

H.3.4 The National Library of Medicine

The National Library of Medicine (NLM) provides Integrated Advanced Information Systems (IAIMS) "grants to health-related institutions and organizations that seek assistance for projects to plan, design, test and deploy systems and techniques for integrating data, information and knowledge resources into a comprehensive networked information management system that serves the organization's clinical, research, educational and administrative needs".

There are several options for grant support that the Management Information System (MIS) could seek under the NLM's IAIMS program: IAIMS Planning Grants, IAIMS Pilot Study Grants, IAIMS Testing and Evaluation Grants, IAIMS Operations Grants and IAIMS Fellowships.

Applications must be prepared using the Public Health Service (PHS) 398 research grant application instructions and forms (rev. 5/2001). The PHS 398 is available at http://grants.nih.gov/grants/funding/phs398/phs398.html [5].

H.3.5 World Bank

World Bank direct financing for malaria control activities is over US$200 million in more than 25 countries. The issues of specific focus for the Bank within the Partnership are on:

- Working with malaria-affected countries to increase their demand for malaria resources,
- ability to effectively employ additional resources.
- Incorporating malaria into Bank-support Health, Nutrition & Population Sector activities, ensuring government's accord an appropriate level of priority to malaria within the health development efforts.
- Reducing taxes and tariffs, and improving trade and regulation issues relating to mosquito nets, the insecticides required to treat them, and pharmaceuticals.
- Fostering private sector and government partnerships in malaria control to expand coverage and increase effective demand for resources.
- Identifying opportunities to address malaria in non-health sectors (*e.g* infrastructure and agricultural projects, education and Early Childhood Development projects) [6].

H.3.6 Other Potential sources/International AID

Listed below are some additional potential sources of funding for the Malaria Information System. :

H.3.6.1 The Toyota Foundation

The Toyota Foundation is a multipurpose grant-making foundation, which provides financial assistance to research and projects that deal, among many issues, with health. For example, in January 2000, the Toyota Foundation financed several workshops at the Faculty of Tropical Medicine, Mahidol University, Thailand with the main theme on "The diagnosis and control of malaria in Asia and Brazil." [78]

H.3.6.2 Rockefeller Foundation

The Rockefeller Foundation has as one of its main goals to pursue scientific approaches to global health. The Foundation aims to address the health priorities of poor and marginalized people of the world. In the past, the Foundation has given grants to the National Institute of Health (NIH), the Multilateral Initiative on Malaria (MIM), and the Medicines for Malaria Venture (MMV) for the purposes of malaria projects, research, and initiatives [9].

H.3.6.3 ExxonMobil Foundation

The ExxonMobil Foundation is a program that aims to target health issues worldwide. One of the Foundation's main health-related goals is to aid science based research and projects that contribute to the understanding of environmental health and health effects issues. To this end, in 2001 the company continued funding efforts such as the Harvard Malaria Initiative, and the Medicines for Malaria Venture (MMV). Additionally, ExxonMobil teams are working with host governments and the local Roll Back Malaria (RBM) campaigns in Angola, Cameroon, Chad, Equatorial Guinea and Nigeria to identify where the company can make the greatest difference in the fight with malaria [10].

H.3.6.4 World Vision

World Vision is a Christian relief and development organization founded in 1950. Its main goal is to serve the world's poorest children and families. Though World Vision does not currently support any specific Malaria program, HI-STAR could potentially seek funding from World Vision in a manner similar to the World Vision's HOPE Initiative. This initiative was launched in December 2000 and its goal is to alleviate the global impact of HIV/AIDS through prevention, care, and advocacy [11].

Additional information on current funding opportunities for malaria training and research in endemic countries can be found in MIM's website under Funding and Training: (http://mim.nih.gov/english/funding/index.html)

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Glossary of Terms

anaemia	a condition in which the blood is deficient in red blood cells, in hemoglobin, or in total volume
Anopheles	any of a genus (*Anopheles*) of mosquitoes that includes all mosquitoes which transmit malaria to humans
artemisinin	drug derived from the wormwood plant *Artemisia annua*, used in the treatment of severe, multiple-drug-resistant falciparum malaria; relatively cheap to produce, well tolerated, enteral, intravenous, or intramuscular administration; derivative was used in China for centuries, lack of detailed data on its pharmacology and toxicity have delayed approval by Western regulatory agencies
arthropod	any of a phylum (Arthropoda) of invertebrate animals (as insects, arachnids, and crustaceans) that have a segmented body and jointed appendages, a usually chitinous exoskeleton molted at intervals, and a dorsal anterior brain connected to a ventral chain of ganglia
atovaquone	used in conjunction with proguanil HCl for the prevention of *P. falciparum* malaria and the treatment of acute, uncomplicated *P. falciparum* malaria, effective against malaria that is resistant to chloroquine, halofantrine, mefloqine, and amodiaquine
Bacillus thuringiensis israelensis	rod-shaped, spore-forming, aerobic bacterium that is used as an effective pesticide for mosquito larval control
bartonellosis	acute, often fatal bacterial infection (*Bartonella bacilliformis)* which is transmitted from person to person by the bite of a blood-sucking sand fly and is characterized by high fevers and progressive reduction of red blood cells
bio-diversity	biological diversity in an environment as indicated by numbers of different species of plants and animals
biomass	the amount of living matter (as in a unit area or volume of habitat)
bivouac	a usually temporary encampment under little or no shelter
chemoprophylaxis	the prevention of infectious disease by the use of chemical agents
chloroquine	an antimalarial drug $C_{18}H_{26}ClN_3$ administered as the bitter crystalline diphosphate
cholera	any of several diseases of humans and domestic animals usually marked by severe gastrointestinal symptoms; *especially* **:** an acute diarrheal disease caused by an enterotoxin produced by a comma-shaped gram-negative bacillus (*Vibrio cholerae* syn. *V. comma*) when it is present in large numbers in the proximal part of the human small intestine

co-artemether	a relatively new anti-malarial combination drug (artemether and lumefantrine) which is being used in the treatment of acute, uncomplicated *P. falciparum* malaria in India
crepuscular	of, relating to, or resembling twilight
dengue fever	an acute infectious disease caused by an arbovirus, transmitted by *Aedes* mosquitoes, and characterized by headache, severe joint pain, and a rash
diurnal	recurring every day
Ebola	an RNA virus (genus *Filovirus* of the family Filoviridae) of African origin that causes an often fatal hemorrhagic fever
eco-epidemiology	study of the relationships between dynamics of environment and health as opposed to simple cause and effect
El Niño	describes the warm phase of a naturally occurring sea surface temperature oscillation in the tropical Pacific Ocean. This oscillation is associated with the atmosphere, and thus the term ENSO – which incorporates the southern oscillation phenomenon - is commonly used.
endemic	present in a community at all times but in relatively low frequency, is typically restricted or peculiar to a locality or region.
endemicity	belonging or native to a particular people or country or characteristic of or prevalent in a particular field, area, or environment
epidemic	more than the expected number of cases of disease occurring in a community or region during a given period of time. A sudden severe outbreak within a region or a group.
epidemicity	the quality or state of being epidemic; the relative ability to spread from one host to others
epidemiological	(1) a branch of medical science that deals with the incidence, distribution, and control of disease in a population (2) the sum of the factors controlling the presence or absence of a disease or pathogen
gametocytes	a cell (as of a protozoan causing malaria) that divides to produce
geostationary	being or having an equatorial orbit requiring an angular velocity the same as that of the Earth so that the position of a satellite in such an orbit is fixed with respect to the Earth
halofantrine	a relatively new drug (FDA approved in 1992) being used to treat mild to moderate malaria
host	a living animal or plant affording subsistence or lodgment to a parasite
immunization	immunity acquired by transfer of antibodies (as by injection of serum from an individual with active immunity)
in situ	in the natural or original position or place
larva	the immature, wingless, and often wormlike feeding form that hatches from the egg of many insects, alters chiefly in size while passing through several molts, and is finally transformed into a pupa or chrysalis from which the adult emerges
larvicides	an agent for killing larval pests
lymphatic filariasis	an arthropod-borne parasitic infection of the lymphatics or connective tissue caused by nematodes (*Wuchereria bancrofti, Brugia malayi,* and

	Brugia timori).
malariae	malaria caused by *P. malariae* which occurs at relatively low frequencies in many regions with endemic malaria
Malarone	brand name for the anti-malarial drug combination: Atovaquone; Proguanil Hydrochloride, for most information, see atovaquone or proguanil.
mefloquine	drug used in the prevention of chloroquine-resistant *P. falciparum* and *P. vivax* malaria infections and the treatment of mild to moderate acute malaria caused by *P. falciparum* or by *P. vivax*; however, strains of *Plasmodium falciparum* resistant to mefloquine are known to exist
meningitis	a usually bacterial disease in which inflammation of the meninges occurs
merozoites	a sporozoan trophozoite produced by schizogony that is capable of initiating a new sexual or asexual cycle of development
morbidity	a diseased condition or state, the incidence of a disease or of all diseases in a population
morbidity	the relative incidence of disease
mortality	the death rate; the ratio of the total number of deaths to the total population.
parasites	an organism living in, with, or on another organism in parasitism
pathogenic	causing or capable of causing disease
Proguanil	used in conjunction with Atovaquone in the prevention of chloroquine-resistant *P. falciparum* malaria, and for the treatment of acute, uncomplicated *P. falciparum* malaria, effective against malaria that is resistant to chloroquine, halofantrine, mefloqine, and amodiaquine.
pupa	an intermediate usually quiescent stage of a metamorphic insect (as a bee, moth, or beetle) that occurs between the larva and the imago, is usually enclosed in a cocoon or protective covering, and undergoes internal changes by which larval structures are replaced by those typical of the imago
schistosomiasis	Infestation with or disease caused by schistosomes; *specifically* a severe endemic disease of humans in much of Asia, Africa, and So. America marked especially by blood loss and tissue damage
Southern oscillation	refers to a seesaw shift in surface air pressure at Darwin, Australia and the South Pacific Island of Tahiti. When the pressure is high at Darwin it is low at Tahiti and vice versa. El Niño, and its sister event – La Niña – are the extreme phases of the southern oscillation, with El Niño referring to a warming of the eastern tropical Pacific, and La Niña a cooling.

sporozoites	a usually motile infective form of some sporozoans that is a product of sporogony and initiates an asexual cycle in the new host
St Louis encephalitis	mosquito-borne virus disease transmitted to humans from infected birds and occurs year-round in the southern United States; mild infections characterized by fever and headache; more serious symptoms include; stupor, disorientation, coma, tremors, occasional convulsions and spastic paralysis (elderly at highest risk), no vaccine or specific treatment available
sulfadoxine/pyrimithamine	used for the treatment of chloroquine-resistant *P. falciparum* malaria, rarely used for malaria prevention today due to life-threatening allergic reactions.
Transponder	a radio or radar set that upon receiving a designated signal emits a radio signal of its own and that is used especially for the detection, identification, and location of objects
visceral leishmaniasis	vector-borne (sandfly) parasitic disease caused by *Leishmania* species; an estimated 350 million people worldwide are at risk; classic visceral symptoms include: fever, weight loss, enlarged liver and spleen, anemia, hair loss and dry, thin, scaly and discolored skin
vivax.	malaria caused by *P. vivax* that induces paroxysms at 48-hour intervals

SUMMER SESSION PROGRAM: DESIGN PROJECT

Aksel Straume
Alex Diaz
Alison Jennings
Allison Gandey
Ammon Madsen
Annie Bernard
Anton Ilin
Arisa Ito
Armine Poghjosyan
Artu Ellmann
Atsushi Baba
Atsushi Mamiya
Barbara Brown
Bent Ziegler

Hiroaki Umehara
Jean-Pierre Balley
Johannes van Es
Jonatan Westman
Julielynn Wong
Kevin Kozak
Linh Bui
Manon Larocque
Marc Calon
Martin Stirn
Matteo Alessandrini
Neil Hazan
Arosanyin Olufemi
Patrick Chatard-Moulin

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Bérengère Houdou
Birgit Loecker
Carla Haroz
Damien Theureau
Daniel Escolar Blasco
David Wong
Ed Chester
Edward Anderson
France Mignard Canton
Giuseppe Ottavianelli
Ha Viet Nguyen
Hammad Benchekroun

Philippe James
Pier Bargellini
Rémi Canton
Sabri Mekaoui
Shane O'Sullivan
Simona Zoffoli
Soraya Ellouze
Stephan Saupe
Sylvain Teodomante
Thibaut Girard
Thierry Pichon
Wencke van der Meulen
Yuri Takaya

Co-chairs
U.R. Rao, Vern Singhroy, Olga Zhdanovich

Faculty
James Burke, Walter Peeters, Ray Williamson

Teaching Assistant
Richard Giroux

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